Stormwater Treatment Technical Requirements Manual

Issued November 2000

City of Seattle

Title 22.800 Stormwater, Grading & Drainage Control Code

Volume 1: Source Control Technical Requirements Manual
Volume 2: Construction Stormwater Control Technical Requirements Manual
Volume 3: Flow Control Technical Requirements Manual
Volume 4: Stormwater Treatment Technical Requirements Manual

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(formerly the Department of Design, Construction and Land Use)

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Location: Seattle Municipal Tower, 20th floor
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STORMWATER FACILITIES, SOURCE CONTROL & SURFACE WATER

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City of Seattle

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PREFACE

This manual presents approved methods, criteria, and details for analysis and design of water quality facilities pursuant to the Seattle Municipal Code, Chapter 22.800 – 22.808, *Stormwater, Grading and Drainage Control.*

Context

Seattle's creeks, lakes, and bays play an important role in the quality of life of the people who live, work and play in the Puget Sound region. Many swim, boat, and fish in these waters, and many others enjoy the plants and wildlife these aquatic habitats support. However, these waters are vulnerable to pollution from a wide variety of human activities. Every home and every place of business within Seattle drains to a creek, lake or bay. Spills or debris may be washed from properties into the public drainage system and flow to these aquatic habitats.

Under the Federal Clean Water Act mandates, the Washington State Department of Ecology's administers the National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit. As a condition of the City of Seattle's NPDES permit, the City regulates development and land use activities that impact the quality and quantity of stormwater runoff through the Seattle Municipal Code, *Stormwater, Grading and Drainage Control Code* (SGDC Code).

In addition to fulfilling requirements of the City's municipal stormwater NPDES permit, the SGDC Code is intended to accomplish the following:

- Protect, to the greatest extent practicable, life, property, and the environment
- Protect the public interest in drainage and related functions of drainage basins, water courses, and shoreline areas
- Protect surface waters and receiving waters
- Fulfill the responsibilities of the City as trustee of the environment for future generations.

The SGDC Code outlines the City's authority to require treatment of stormwater runoff from large projects, which are defined as including 5,000 square feet or more of new or replaced impervious surface or 1 acre or more of land disturbing activity.

Purpose of this Rule

This technical document is intended to provide technical requirements for designing, constructing and maintaining treatment facilities prescribed in the Seattle Municipal Code, SMC Chapter 22.800 – 22.808, *Stormwater, Grading and Drainage Control Code*. Treatment requirements are designed to remove certain pollutants from stormwater runoff before they are able to enter a receiving water body, such as a creek, lake, bay or river.

How this Manual is Organized

The information in this chapter is organized into the following eight main chapters and two appendices:

- Chapter 1, "**Requirements and Treatment Facilities**" (p. 1), summarizes requirements for treatment as contained in the Stormwater, Grading and Drainage Control Code, and describes the types of stormwater treatment facilities that may be used to meet the requirements.
- Chapter 2, "**General Requirements for Stormwater Treatment** Facilities" (p. 11) presents general design requirements and details pertinent to all water quality facilities.
- Chapter 3, "**Biofiltration Facility Designs**" (p. 35), presents the details for analysis and design of biofiltration facilities such as biofiltration swales and filter strips.
- Chapter 4, "**Wetpool Facility Designs**" (p. 68), presents the details for analysis and design of wetpool water quality facilities such as wetponds, wetvaults, stormwater wetlands, and combinations of these facilities with detention facilities.
- Chapter 5, "**Media Filtration Facility Designs**" (p. 111), presents the details for analysis and design of filtration facilities such as sand filters and leaf compost filters.
- Chapter 6, "**Oil Control Facility Designs**" (p. 145), presents the details for analysis and design of oil control facilities such as catch basin inserts and oil/water separators.
- Chapter 7, "**Landscape Management Plan**" (p.161), contains guidelines for preparing a Landscape Management Plan.
- Chapter 8, "**Alternative Treatment Technologies**" (p. 167) presents the protocol for accepting an alternative technology for meeting the runoff treatment requirements.
- Appendix A, "**Hydrologic Analysis**," provides information on using the Santa Barbara Unit Hydrograph method for determining runoff volumes and peak flows.
- Appendix B, "**Facility Maintenance Requirements**," contains inspection and maintenance checklists for stormwater treatment facilities.

DEFINITIONS

The following are selected definitions contained in the City of Seattle's *Stormwater, Grading and Drainage Control Code* (SMC 22.800 – 22.808).

Biofiltration swale means a long, gently sloped, vegetated channel designed and maintained to treat stormwater runoff through sedimentation, adsorption, and biological uptake. Grass is the most common vegetation, but wetland vegetation can be used if the soil is saturated.

Civil engineer, licensed means a person who is a licensed by the State of Washington to practice civil engineering.

Coalescing plate oil/water separator means a multi-chambered vault, containing a set of parallel, corrugated plates that are stacked and bundled together in the center of the vault. Coalescing plate separators are designed to remove dispersed oil and floating debris as well as in containing spills.

Containment area means the area designated for conducting high-risk pollution generating activities for the purposes of implementing operational source controls or designing and installing structural source controls or treatment facilities.

Design storm means a rainfall event used in the analysis and design of drainage facilities.

Development means land disturbing activity or the addition or replacement of impervious surface.

Director means the Director of the Department authorized to take a particular action, and the Director's designees, who may be employees of that department or another City department.

Filter strip means a gently sloping vegetated area that is designed and maintained to treat, through sedimentation, adsorption and biological uptake, stormwater runoff from overland sheet flow from adjacent paved areas before it concentrates into a discrete channel.

Flow Control Facility means a method for controlling the discharge rate of stormwater runoff from a site.

Geotechnical engineer, experienced or **Geotechnical/Civil engineer, experienced** means a professional civil engineer licensed by the State of Washington who has at least four years of professional experience as a geotechnical engineer, including experience with landslide evaluation.

High-risk pollution generating activities are the following:

1. Fueling operations that involve transferring fuel into mobile vehicles or equipment at permanent stations, temporary stations, and mobile fueling stations. Permanent stations include facilities, such as, but not limited to, commercial gas stations, maintenance yards, and private fleet fueling stations, where fuel is transferred from a dedicated fueling station. Temporary fueling stations include, but are not limited to, construction sites and any other site where fuel is temporarily stored and dispensed into vehicles or equipment. Mobile fueling stations are fueling operations where fuel is delivered to vehicles and equipment via mobile tank trucks.
2. Vehicle, equipment or building washing or cleaning, including any of the following: mobile vehicle steam cleaning operations or vehicle washing at commercial car wash facilities, charity car washes, or permanent parking lots such as new, used, and rental car lots and fleet lots; outside washing of tools or other manufacturing equipment; outside

cleaning of commercial cooking equipment such as filters and grills; or washing of buildings, including exteriors or mobile interior building cleaning services.

3. Truck or rail loading or unloading of liquid or solid materials that involves transferring non-containerized bulk liquids from truck or rail, or loading/unloading materials at a commercial or industrial loading dock.
4. Liquid storage in stationary above ground tanks, including storing liquid chemicals, fertilizers, pesticides, solvents, grease, or petroleum products in stationary above ground tanks.
5. Outside portable container storage of liquids, food wastes, or dangerous wastes including storing any of the following: vegetable grease, animal grease, or other accumulated food wastes; used oil; liquid feedstock; cleaning compounds; chemicals; solid waste as defined by SMC 21.36; or dangerous waste.
6. Outside storage of non-containerized materials, by-products, or finished products, including outside storage of any of the following: non-liquid pesticides or fertilizers; contaminated soil; food products or food wastes; metals; building materials, including but not limited to lumber, roofing material, insulation, piping, and concrete products; or erodible materials, including but not limited to sand, gravel, road salt, topsoil, compost, excavated soil, and wood chips.
7. Outside manufacturing activity including any of the following: processing; fabrication; repair or maintenance of vehicles, products or equipment; mixing; milling; refining; or sand blasting, coating, painting, or finishing of vehicles, products, or equipment.
8. Landscape construction or maintenance, including any of the following: land disturbing activities as described in SMC 22.801.130; fertilizer or pesticide application near public drainage control system; and disposal of yard waste near a public drainage control system or riparian corridor.

High-use means any project planned to generate or accommodate any of the following:

1. Expected average daily traffic (ADT) count equal to or greater than 100 vehicles per 1,000 square feet of gross building area. In addition, the following is high-use unless the responsible party demonstrates to the satisfaction of the Director of DCLU or of the Director of SPU that the project will generate less than 100 vehicles per 1,000 square feet of gross building area: uncovered parking lot accessory to any fast-food restaurant, convenience market, supermarket, shopping center, discount store, movie theater, athletic club, or bank.
2. Petroleum storage or transfer in excess of 1,500 gallons per year, not including delivered heating oil.
3. Storage, or maintenance of a fleet of 25 or more diesel vehicles that are over 10 tons net weight (including, but not limited to, trucks, buses, trains, heavy equipment).
4. Road intersections with a measured ADT count of 25,000 vehicles or more on the main roadway and 15,000 or more on any intersecting roadway, excluding projects proposing primarily pedestrian or bicycle use improvements.

Impervious Surface means any surface exposed to rainwater from which most water runs off including, but not limited to, paving, packed earth material, oiled macadam, or other treated surfaces, and roof surfaces, patios, and formal planters.

Infiltration facility means a drainage facility that temporarily stores, and then percolates stormwater runoff into the underlying soil. Examples include but are not limited to infiltration trenches, ponds, vaults, and tanks.

Land Disturbing Activity means any activity that results in a movement of earth, or a change in the existing soil cover (both vegetative and nonvegetative) or the existing topography. Land disturbing activities include, but are not limited to, clearing, grading, filling, excavation, or addition or replacement of impervious surface..

Large Project means a project including 5,000 square feet or more of new or replaced impervious surface or 1 acre or more of land disturbing activity.

Media filter means a stormwater treatment system that utilizes a filtration medium such as sand or leaf compost to remove pollutants via physical filtration and chemical adsorption or precipitation. Filters may be constructed underground in a vault or above ground in a pond. In both systems, stormwater that has passed through the filter media is collected in an underground pipe and discharged to the nearby drainage system.

Oil/water separator means a structure, usually underground, that is designed to provide quiescent flow conditions so that globules of free oil or other floatable materials that may be present in stormwater can float to the water surface and become trapped in the structure.

Oil/water separator, American Petroleum Institute (API) means a vault that has multiple chambers separated by baffles and weirs to trap oil in the vault. API oil/water separators are designed to remove dispersed oil and floating debris and in containing spills.

Project means the addition or replacement of impervious surface or the undertaking of land disturbing activity on a site.

Public combined sewer means a publicly owned and maintained sewage system which carries drainage water and sewage and flows to a publicly owned treatment works.

Public storm drain means the part of a public drainage control system which is wholly or partially piped, is owned or operated by a public entity, and is designed to carry only drainage water.

Replaced impervious surface or **replacement of impervious surface** means impervious surface that is removed down to earth material and a new impervious surface is installed.

Sand filter means a depression or basin with the bottom made of a layer of sand designed and maintained to filter pollutants. Stormwater is treated as it percolates through the sand layer.

Site means the-lot or parcel, or portion of street, highway or other public right-of-way, or contiguous combination thereof, where a permit for the addition or replacement of impervious surface or the undertaking of land disturbing activity has been issued or where any such work is proposed or performed. For development limited to a public street, each segment from mid-intersection to mid-intersection shall be considered a separate site.

Wetpool means a permanent pool of water that is contained in the bottom of a wet pond or wet vault stormwater treatment facility. Water in the wetpool is normally lost only through evaporation, evapotranspiration, or slow infiltration into the ground. The wetpool, also referred to as dead storage, is designed to reduce the velocity of incoming stormwater flows, encouraging particulates and particulate-bound pollutants to settle in wet ponds and wet vaults.

Wetpond and **wetvault** mean stormwater treatment facilities that contain a permanent pool of water (wetpool). They are designed to settle out particles of fine sediment, and allow biologic activity to occur to metabolize nutrients and organic pollutants, by providing a long retention time. Wetvaults are covered by a lid.

1 REQUIREMENTS AND TREATMENT FACILITIES

This chapter of the Directors' Rule for stormwater treatment summarizes the requirements for installing treatment facilities during a development or redevelopment project. A **basic stormwater treatment facility** is required to be installed on any new or redevelopment project that exceeds the **treatment requirement threshold** described below. A **high-use site stormwater treatment facility** is required *in addition to* the basic stormwater treatment facility if the treatment requirement threshold is exceeded *and* the site meets one or more of the criteria defining a **high-use site** (See "Definitions"). Figure 1 is a flow diagram summarizing the conditions under which a stormwater treatment facility is required to be installed.

The requirements contained in this Directors' Rule are a subset of the treatment requirements contained in the Seattle Municipal Code, Chapter 22.800 – 22.808, *Stormwater, Grading and Drainage Control.* Where differences exist between the more inclusive Code language and the requirements described in the Rule, the language in this Rule shall govern. The requirements described below narrow the treatment requirement applicability, and have been developed acknowledging current regional treatment standards, which specify that: (1) facilities should be designed to treat drainage from pollution-generating surfaces; and (2) treatment requirements appropriately differ between redevelopment and new development. Consistent with this acknowledgement, the City has committed to develop a Water Quality Improvement Plan that will consider the appropriate application of treatment facilities *as part* of a broader program to improve water quality in Seattle. This commitment, and the treatment requirements prescribed in this rule, have been approved by the Washington Department of Ecology and are consistent with the *Stormwater, Grading and Drainage Control Code.*

> *The Director of SPU may ask the Washington State Department of Ecology to approve a commitment by the City to develop a water quality improvement plan to identify pollutants of concern and associated sources, prioritize drainage basins, and evaluate alternative improvement strategies. After such approval and consistent with its terms, the Directors may grant exceptions to or make inapplicable the treatment requirements of this Section 22.802.016 B2, pursuant to rules promulgated by the Directors.*
>
> (SMC 22.802.016.B.2.f)

REQUIRED VS. RECOMMENDED DESIGN CRITERIA

Both required and recommended design criteria are presented in this Rule. Criteria stated using "shall" or "must" are required design criteria and generally affect facility performance or critical maintenance factors. These design criteria are mandatory unless approval is obtained from

- DCLU if the deviation involves design or construction, or
- SPU if the deviation involves post-construction operation or maintenance.

Adjustments to the requirements of this manual may be granted provided that granting the adjustments will achieve the following:

- Produce a compensating or comparable result that is in the public interest; *and*

- Meet the objectives of safety, function, appearance, environmental protection, and maintainability, based on sound engineering judgment.

Sometimes options are stated as part of the required design criteria using the language **"should"** or **"may."** These latter criteria are really **recommended design criteria**, but are so closely related to the required criteria that they are placed with it. In some cases **recommended design features** are presented under a separate heading in the "Design Criteria" sections.

Use of Figures: The figures provided in this manual give **one example** of how the stormwater treatment facility design criteria may be applied. There may be other engineering solutions that also meet the design criteria. Those options are also allowed unless it is the judgment of DCLU that the option has other problems that render it a poor engineering choice. Although the figures are meant to illustrate many of the most important design criteria, they may not show **all** criteria which apply. In general, the figures are not used to specify requirements unless they are indicated elsewhere in the manual.

1.1 REQUIREMENT TO INSTALL TREATMENT FACILITIES

Projects are not subject to the stormwater treatment requirements prescribed in the *Stormwater, Grading and Drainage Control Code* (Seattle Municipal Code, SMC 22.800 – 22.808) if no stormwater runoff is produced or if the project discharges to the public combined sewer system.

> *Stormwater treatment facilities shall be installed and maintained to treat that portion of the site being developed…unless the following conditions exist:*
>
> - *The site produces no stormwater runoff discharge as determined by a licensed civil engineer; or*
> - *The entire project drains to a public combined sewer.*
>
> (SMC 22.802.016.B.2.a)

If neither of the conditions above can be met, installation of a treatment facility will be required if the project exceeds any of the **treatment requirement thresholds** described below.

1.1.1 Treatment Requirement Thresholds

BASIC TREATMENT REQUIREMENT THRESHOLD

On any new development or redevelopment project, a **basic stormwater treatment facility** must be installed to treat any of the following surfaces:

1. **5,000 square feet** or more *new*, or **one acre** of accumulative *new and replaced*:
   a) Roof made with uncoated metal products;

b) Road surface accessible by vehicle, including bike lanes within that portion of the roadway accessible by vehicle;

c) Uncovered portion of paved driveway;

d) Uncovered portion of parking lot, including all areas accessible by vehicle;

e) Unfenced fire lane; or

f) Airport runway.

2. **One acre** of accumulative *new and replaced* **vegetative cover or exposed soil** subject to the use of pesticides and fertilizers, including lawns, golf courses, landscaped areas, parks and sports fields, unless a **landscape management plan** is submitted and approved by the Director.

3. The **containment area** for the following **high-risk pollution generating activitie**s, unless source control is provided according to the City of Seattle's Source Control Technical Requirements Manual:

   a) Wash pads;

   b) Uncovered outside storage of non-containerized storage of materials, by-products or finished products; or

   c) Uncovered outside manufacturing activity.

BASIC STORMWATER TREATMENT FACILITIES

The *Stormwater, Grading and Drainage Control Code* lists seven different types of basic stormwater treatment facilities. One of these must be installed and maintained if the basic treatment requirement threshold is exceeded, unless an alternative technology is proposed and accepted.

> *One of the following stormwater treatment facilities shall be installed and maintained in accordance with rules promulgated jointly by the Directors: infiltration, wetpond, stormwater wetland, biofiltration swale, filter strip, wet vault, media filter, or an alternative technology….*
>
> (SMC 22.802.016.B.2.c)

Basic Stormwater Treatment Facilities are further described in Section 1.2.2 and in Chapter 2 through Chapter 5. Policies for using alternative treatment technologies are described in Section 1.1.2 and Chapter 8.

HIGH-USE SITE STORMWATER TREATMENT FACILITIES

If a site meets the Basic Treatment Requirement Threshold *and* meets the criteria described in the definition for "high-use site," then a high-use site stormwater treatment facility shall be installed in addition to a basic treatment facility.

> ***High-use*** *means any project planned to generate or accommodate any of the following:*
>
> 1. *Expected average daily traffic (ADT) count equal to or greater than 100 vehicles per 1,000 square feet of gross building area. In addition, the following is high-use unless the responsible party demonstrates to the satisfaction of the Director of DCLU or of*

> *the Director of SPU that the project will generate less than 100 vehicles per 1,000 square feet of gross building area: uncovered parking lot accessory to any fast-food restaurant, convenience market, supermarket, shopping center, discount store, movie theater, athletic club, or bank.*
>
> 2. *Petroleum storage or transfer in excess of 1,500 gallons per year, not including delivered heating oil.*
>
> 3. *Storage, or maintenance of a fleet of 25 or more diesel vehicles that are over 10 tons net weight (including, but not limited to, trucks, buses, trains, heavy equipment).*
>
> 4. *Road intersections with a measured ADT count of 25,000 vehicles or more on the main roadway and 15,000 or more on any intersecting roadway, excluding projects proposing primarily pedestrian or bicycle use improvements.*
>
> *(SMC 22.801.090 "H")*
>
> *For high use sites, one of the following stormwater treatment facilities shall be installed and maintained in accordance with rules promulgated by the Director in addition to the other required treatment facilities: coalescing plate oil/water separator; media filter, API oil/water separator; or an alternative technology….*
>
> (SMC 22.802.016.B.2.d)

High-Use Site Treatment Facilities are further described in Section 1.2.3 and in Chapter 5 and Chapter 6. Policies for using alternative treatment technologies are described in Section 1.1.2 and Chapter 8.

1.1.2 Use of an Alternative Technology

An alternative to a prescribed stormwater treatment facility can be proposed for a project. Alternative technologies can include both structural and non-structural approaches for removing pollutants from stormwater before it leaves the site.

> *Alternative technology to meet runoff treatment requirements may be permitted if the following criteria are met:*
>
> i. *Treatment effectiveness monitoring is conducted, which requirement may be waived if sufficient research has been conducted to demonstrate to the Director of SPU's satisfaction that an alternative technology offers equivalent protection*
>
> ii. *Monitoring and maintenance records are reported to the Director of SPU at the end of each of the first three years following installation; and*
>
> iii. *The applicant demonstrates to the Director of SPU 's satisfaction that the alternative will provide protection equivalent to the methods prescribed in the applicable subsections* of this code.
>
> (SMC 22.802.016.B.2.e)

Chapter 8 (p. 167) describes the general policies and procedures for proposing and evaluating alternative technologies.

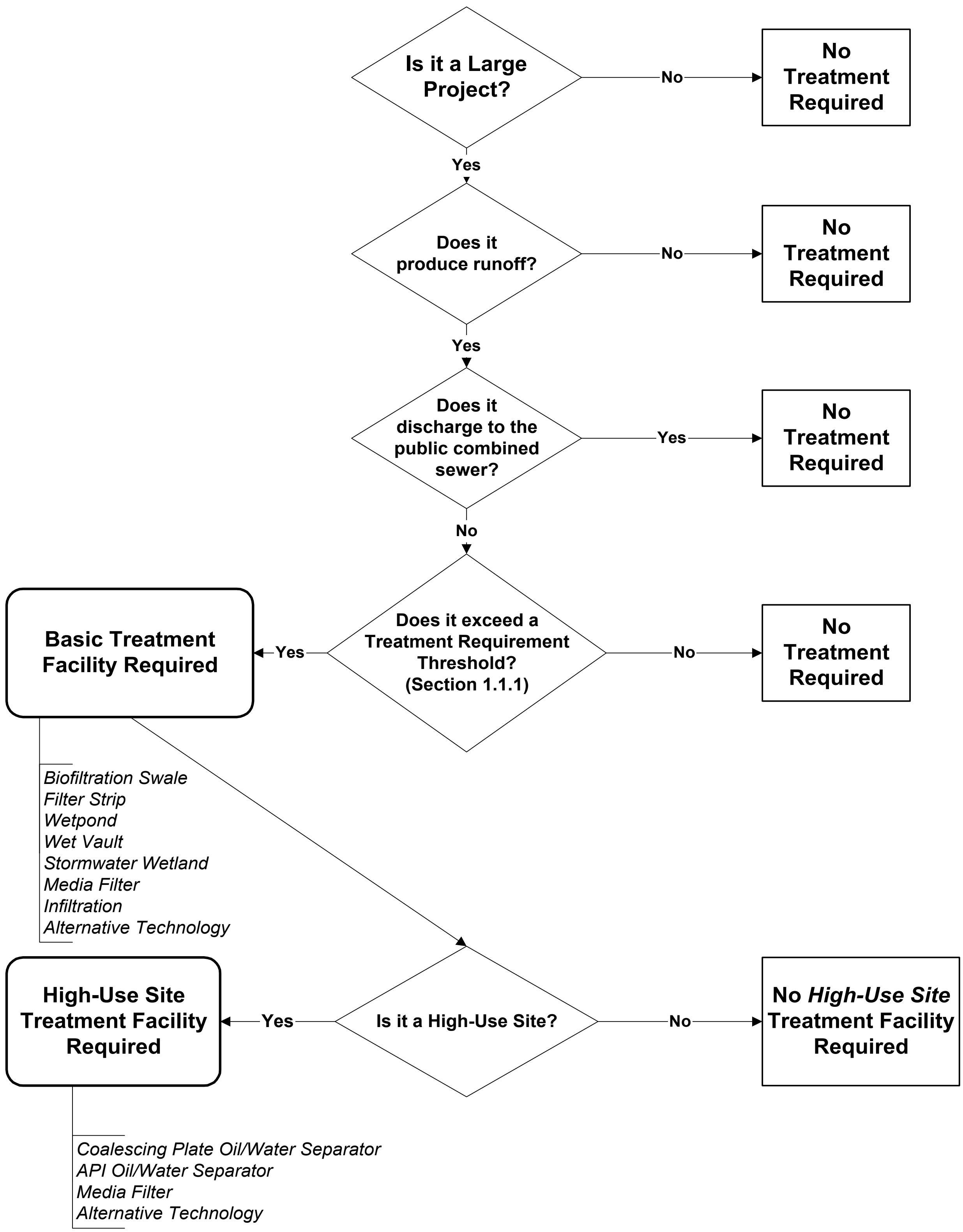
1.1.3 Use of a Landscape Management Plan

An alternative to a prescribed stormwater treatment facility can be proposed for a project involving new and replaced vegetative cover or exposed soil subject to the use of pesticides and fertilizers. Landscape Management Plans are discussed in Chapter 7 (p. 161).

1.1.4 Use of an Integrated Drainage Plan

The Department of Ecology has approved the option of an Integrated Drainage Plan as an equivalent means of complying with the treatment requirement in the Stormwater Code. An integrated drainage plan means a drainage control plan that substitutes water quality treatment from one or more projects through the design of and installation of offsite facilities within a basin draining to the same receiving water body. Participation in an Integrated Drainage Plan must be approved by the Director of SPU through an agreement that includes specific applicant contributions and a construction start date not to exceed five years from the date of approval. Additional conditions, criteria and implementation procedures governing Integrated Drainage Plans may be required by the Director pursuant to future rule amendments..

FIGURE 1. TREATMENT FACILITY REQUIREMENTS FLOW CHART



1.2 STORMWATER TREATMENT FACILITIES

This section identifies facility choices for meeting the treatment requirement of the *Stormwater, Grading and Drainage Control Code*. Stormwater treatment facilities must be sized to treat flows based on the **water quality (WQ) design storm**. One of the **basic stormwater treatment facilities** must be used on any large project meeting or exceeding the **treatment requirement threshold** described above. A **high-use treatment facility** is required on any large project exceeding the treatment requirement threshold and having high-use site characteristics as defined in the *Stormwater, Grading and Drainage Control Code.*

1.2.1 Water Quality Design Storm

Both basic and high-use site stormwater treatment facilities must be designed based on the flows generated from the **water quality design storm**.

> *Stormwater treatment facilities shall be designed to treat the runoff volume from the 6-month, 24-hour storm, collected from the drainage area being routed through the facility.*
>
> (SMC 22.802.016.B.2.b)

Section 2.1 (p. 11) and Appendix A provide additional information on the Water Quality Design Storm.

1.2.2 Basic Stormwater Treatment Facilities

There are seven basic stormwater treatment facility options, any one of which may be chosen to satisfy the basic treatment requirements of the *Stormwater, Grading and Drainage Control Code*.[1] Treatment facility options to meet the high-use site treatment requirements are described in the next section.

❑ BASIC TREATMENT FACILITY OPTION 1 ¾ BIOFILTRATION SWALE

A *biofiltration swale* is a long, gently sloped, vegetated ditch designed to filter pollutants from stormwater. Grass is the most common vegetation used. Design details are given in Section 3.1 (p. 35). The wet biofiltration swale (see Section 3.2, p. 52) is a variation of the basic biofiltration swale for use where the longitudinal slope is slight (1% to 2% or less), water tables are high, or continuous low base flow is likely to result in saturated soil conditions. Under such conditions, healthy grass growth is not possible; wetland plants are used to provide the biofiltration mechanism in saturated soil conditions. The continuous inflow biofiltration swale (see Section 3.3, p. 55) may be used in situations such as roadways where water enters the swale continuously rather than at one discrete inflow point. Table 1 summarizes when the biofiltration swale and its variations are to be applied.

[1] Note: The King County *Surface Water Design Manual* (1998) refers to "treatment goals" based on a percentage removal of total suspended solids. Treatment goals are not contained in the City of Seattle *Stormwater, Grading and Drainage Control Code*.

❑ BASIC TREATMENT FACILITY OPTION 2 ¾ FILTER STRIP

A *filter strip* is a grassy area with gentle slopes which treats stormwater runoff from adjacent paved areas before it concentrates into discrete channels; see Section 3.4 (p. 56) for design details. The narrow area filter strip may be used along a roadway or parking lot in limited space situations as specified in Section 3.5 (p. 65).

❑ BASIC TREATMENT FACILITY OPTION 3 ¾ WETPOND

Wetponds are stormwater ponds that maintain a pool of water for most of the year. Stormwater entering the pond is treated during the relatively long residence time within the pond. The sizing method used in this manual is based on a method developed by the Nationwide Urban Runoff Program (NURP). The basic wetpond has a volume three times larger than the volume of runoff from NURP's mean annual storm.[2] See Section 4.1 (p. 68) for design details.

❑ BASIC TREATMENT FACILITY OPTION 4 ¾ WETVAULT

An underground vault may be used to comply with the basic stormwater treatment facility requirement . The treatment volume is the same as for the wetpond. See Section 4.2 (p. 90) for design details.

❑ BASIC TREATMENT FACILITY OPTION 5 ¾ STORMWATER WETLAND

A *stormwater wetland* uses biological processes of plant uptake and bacterial degradation as well as physical and chemical processes and gravity settling to remove pollutants. The footprint of the stormwater wetland is sized based on the wetpond sizing, but the depth of water in the second cell is reduced to encourage plant growth; see Section 4.3 (p. 98) for design details.

❑ BASIC TREATMENT FACILITY OPTION 6 ¾ MEDIA FILTER

Media filters pass the runoff through a material that removes pollutants through filtration, ion exchange, adsorption, or microbial degradation. A *sand filter* is a depression or pond with the bottom made of a layer of sand. Stormwater is treated as it percolates downward through the sand layer. Sand filters can be built as open ponds, underground vaults, or linear perimeter trenches. See Section 5.2 (p. 113) for sand filters, Section 5.3 (p. 131) for sand filter vaults, and Section 5.4 (p. 137) for linear sand filters. Filter systems using media other than sand can also be used to treat stormwater runoff. Section 5.5 (p. 142) describes the Stormfilter™ treatment system.

❑ BASIC TREATMENT FACILITY OPTION 7 ¾ INFILTRATION

Using infiltration as a method for treating contaminated stormwater runoff is an option allowed by the *Stormwater, Grading and Drainage Control Code*. However, infiltration facilities must be designed with care, owing to the types of soils typical in the City of Seattle and risks of damage to adjacent properties. Percolation tests are required to ensure the facility will properly treat the water quality design storm. Additionally, the infiltrate leaving the facility cannot exceed ground water quality standards, and it cannot adversely impact adjacent properties. Owing to the site-specific nature of infiltration treatment facilities and the City’s general interest in evaluating the use of such facilities, a project proposing to use infiltration for treatment must be reviewed and assessed as an Alternative Treatment Technology, using the criteria and protocols contained in Chapter 8.

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[2] The mean annual storm is derived from dividing the annual rainfall (in inches) by the number of storms per year.

TABLE 1. SELECTION OF BIOFILTRATION SWALE TYPE APPROPRIATE FOR SITE	
Site Circumstances	**Biofiltration Swale Type**
Flow enters at head of swale • Longitudinal slope 1% or less *or* • Located downstream of a Level 2 or 3 detention facility	Wet biofiltration swale (Section 3.2, p. 52)
Flow enters at head of swale • Longitudinal slope between 1 and 2% • Soil saturation or base flows likely in wet season	*Either* wet biofiltration swale (Section 3.2), *or* basic biofiltration swale (Section 3.1, p. 35), depending on site; may require underdrain or low-flow drain.
Flow enters at head of swale • Longitudinal slope ≥ 2% • Base flows may or may not be likely in wet season • Not downstream of Level 2 or 3 detention.	Basic biofiltration swale (Section 3.1, p. 35); may require low-flow drain, depending on site
Along a roadway or parking lot with: • Continuous inflow into the biofilter, *or* • Numerous discrete inflows with no single inflow contributing more than about 10% of total swale flow.	Continuous inflow biofiltration swale (Section 3.3, p. 55)

1.2.3 High-Use Site Treatment Facilities

A high-use stormwater treatment facility is required for all new and redevelopment projects that exceed one of the **treatment requirement thresholds** described in the Rule *and* have **high-use site** characteristics (see "Definitions"). Oil control devices are to be placed upstream of other facilities, as close to the source of oil generation as practical. High-use stormwater treatment facilities are **in addition to** the Basic Stormwater Treatment requirement.

❑ HIGH-USE SITE OPTION 1 ¾ BAFFLE OIL/WATER SEPARATOR (API)

Baffle oil/water separators (see Section 6.1, p. 145) may be used to treat stormwater runoff from high-use developments that produce relatively high concentrations of oil and grease. Baffle separators historically have been effective in removing oil having droplet sizes of 150 microns or larger. If sized properly, these facilities can achieve effluent concentrations as low as 10 to 15 mg/L.

❑ HIGH-USE SITE OPTION 2 ¾ COALESCING PLATE OIL/WATER SEPARATOR (CPI)

Coalescing plate separators (see Section 6.1, p. 145) may be used to treat stormwater runoff from high-use developments that produce relatively high concentrations of oil and grease. Current technology and design of coalescing plate separators achieve effluent concentrations of 10 mg/L or lower, removing oil droplet sizes as small as 20 to 60 microns.

❑ HIGH-USE SITE OPTION 3 ¾ MEDIA FILTER

Some media filters may be used to meet the treatment requirements for high-use sites. The linear sand filter (see Section 5.4, (p. 137) may also be used for oil control on the High-Use site. However, if used to satisfy both the basic treatment requirement and high-use treatment requirement, the facility must be inspected at least quarterly, unless specified otherwise by the designer, and maintained as needed. Filter media other than sand may also be used to remove pollutants from high-use sites.

2 GENERAL REQUIREMENTS FOR STORMWATER TREATMENT FACILITIES

This section presents the general requirements for stormwater treatment facilities.

Use of Metal Materials

Galvanized metals leach zinc into the environment, especially in standing water situations. High zinc concentrations, sometimes in the range that can be toxic to aquatic life, have been observed in the region.[3] Therefore, use of galvanized materials in stormwater facilities and conveyance systems is discouraged. Where other metals, such as aluminum or stainless steel, or plastics are available, they should be used.

2.1 WATER QUALITY DESIGN FLOWS

Santa Barbara Urban Hydrograph Method

The Santa Barbara Urban Hydrograph (SBUH) method was developed by the Santa Barbara County Flood Control and Water Conservation District to determine a runoff hydrograph for an urbanized area. It is a simpler method than some other approaches, as it computes a hydrograph directly. The SBUH method is a popular method for calculating runoff, since it can be done with a spreadsheet or by hand relatively easily. When on-site stormwater treatment is required, the SBUH method shall be the only hydrologic *event* calculation method used to determine the water quality design flow. The SBUH method depends on several variables:

- Pervious and impervious areas;
- Time of concentration calculations;
- Runoff curve numbers applicable to the site;
- Design storm.

The proper selection of homogeneous basin areas is required to obtain the highest degree of accuracy in the hydrograph analysis. Significant differences in land use within a given draining basin must be addressed by dividing the basin area into subbasin areas of similar land use and/or runoff characteristics. Hydrographs should then be computed for each subbasin area and summed to form the total runoff hydrograph for the basin. To further enhance the accuracy of hydrograph analysis, all pervious and impervious areas within a given basin or subbasin shall be analyzed separately. This may be done by computing separate hydrographs for each area and combining them to form the total runoff hydrograph.

Time of concentration, TC, is the time for a theoretical drop of water to travel from the furthest point in the drainage basin to the facility being designed. In this case, TC is derived by calculating the overland flow time of concentration and the channelized flow time of

[3] Finlayson, 1990. Unpublished data from reconnaissance of Metro Park and Ride lot stormwater characteristics.

concentration. TC depends on several factors, including ground slope, ground roughness, and distance of flow.

The Soil Conservation Service (SCS) runoff curve number to be used with the SBUH method shall be 98 for impervious surfaces, and 85 or greater for pervious surfaces unless one of the following conditions is met:

- A lower SCS curve number is justified for an area incorporating one or more site design options (see City of Seattle Directors' Rule for Flow Control), or
- A soil report by an experiences geotechnical/civil engineer indicates site soils are sufficiently pervious to allow a smaller SCS curve number to be used.

In the City of Seattle, the design storm used by the SBUH method *for design of treatment facilities* is based on a *standard* SCS Type 1A storm event hyetograph where, during the peak 10-minute period, 5.40% of the total rainfall occurs. Note that *for design of flow control facilities*, a *modified* SBUH method is used where 9.92% of the rainfall occurs during the ten-minute period at the peak of the storm event (see Appendix A).

Water Quality Design Flow

Flow-through treatment structures, such as biofiltration facilities, media filtration facilities, and oil control facilities, must be sized based on runoff from the 6-month, 24-hour storm event, which has a rainfall runoff volume of 1.08 inches. This value is based on the assumption that the 6-month, 24-hour storm volume is 64% of the volume of the 2-year, 24-hour storm event.[4] For these types of facilities, water quality design flow, Q_{wq}, is equal to the peak flow (measured in cfs). Using the SBUH method, this peak occurs during the ten-minute interval between 470 and 480 minutes, when 5.40% of the total rainfall volume occurs. Additional information on the SBUH method is provided in Appendix A. For *storage* treatment facilities, such as wetponds, wetvaults, and stormwater wetlands, sizing is based on the volume of runoff from the *mean annual storm event*, which for Seattle is 0.47 inches. Additional information on determining water quality design flows for storage treatment facilities is contained in Chapter 4.

2.2 SEQUENCE OF FACILITIES

As specified in the water quality menus, where more than one water quality facility is used, the order is often prescribed. This is because the specific pollutant removal role of the second or third facility in a treatment train often assumes that significant solids settling has already occurred. For example, phosphorus removal using a two-facility treatment train relies on the second facility (sand filter) to remove a finer fraction of solids than those removed by the first facility.

There is a larger question, however, of whether water quality facilities should be placed upstream or downstream of detention facilities. In general, all water quality facilities may be installed upstream of detention facilities, although presettling basins are needed for sand filters and infiltration basins. Not all water quality facilities, however, can be located

[4] Ref: Stormwater Management Manual for the Puget Sound Basin; The Technical Manual (1992). Publication 91-75, Washington State Department of Ecology, Olympia. Washington.

downstream of detention facilities. Those facilities that treat unconcentrated flows, such as filter strips and narrow-area biofilters, will seldom be practical downstream of detention facilities. Other facilities present special problems that must be considered before placement downstream is advisable.

Two facilities that fall into this latter category are the basic biofiltration swale (see Section 3.1, p. 35) and the sand filter or sand filter vault (see Sections 5.2 or 5.3). For both of these facilities, the prolonged low flows resulting from flow control may interfere with facility operation. In the case of basic biofilters, prolonged flows, generally in excess of about two weeks, will cause the grass to die. This can be dealt with by using the wet biofilter design.

In the case of sand filters, prolonged flows may result in the sand being saturated for long periods. Saturated sand can become anoxic (lose all oxygen) when dissolved oxygen in the pore water becomes depleted. If the sand layer becomes anoxic, some forms of phosphorus, P, can become soluble and be released, negating the positive P removals achieved earlier. To prevent long periods of sand saturation, adjustments may be necessary after the sand filter is in operation to bypass some areas of the filter, allowing them to drain completely. It may also be possible to employ a different alternative that uses facilities less sensitive to prolonged flows. Table 2 summarizes placement considerations of water quality facilities in relation to detention.

Oil control facilities must be located upstream of water quality facilities and as close to the source of oil-generating activity as possible. They should also be located upstream of detention facilities, if possible.

TABLE 2. WATER QUALITY FACILITY PLACEMENT IN RELATION TO DETENTION		
Water Quality Facility	**Preceding Detention**	**Following Detention**
Basic biofiltration swale (Section 3.1)	OK	Prolonged flows may cause soil saturation and injure grass. If downstream of a detention facility, the wet biofiltration swale may be needed. (see Section 3.2.)
Wet biofiltration swale (Section 3.2)	OK	OK
Continuous inflow biofiltration swale (Section 3.3)	OK	No—must be installed before flows concentrate.
Filter strip or roadway filter strip (Sections 3.4 and 0)	OK	No—must be installed before flows concentrate.
Basic wetpond (Section 4.1)	OK	OK—less water level fluctuation in ponds downstream of detention facility may improve aesthetic qualities.
Basic combined detention and wetpond (Section 4.4)	Not applicable	Not applicable
Wetvault (Section 4.2)	OK	OK
Basic sand filter or sand filter vault (Section 5.2 or 5.3)	OK, but presettling and control of floatables needed	OK—sand filters downstream of a detention facility may require field adjustments if prolonged flows cause sand saturation and interfere with the phosphorus removal mechanism.
Stormwater wetland/pond (Section 4.3)	OK	OK—less water level fluctuation and better plant diversity are possible if the stormwater wetland is located downstream of the detention facility.

2.3 MAINTENANCE ACCESS, SLOPES, & EMBANKMENTS

This section presents the general requirements for water quality facility maintenance access, side slopes, fencing, and embankments.

When locating water quality facilities near wetlands and streams, there is a potential that the water level may be lowered. Care in the design and siting of the facility or conveyance elements associated with the facility is needed to assure this impact is avoided. Sufficient setback of the facility from the water body is one method to prevent impact.

❑ MAINTENANCE ACCESS

Access for maintenance equipment maneuverability must be provided.

❑ SIDE SLOPES, FENCING, AND EMBANKMENTS

Side slopes for water quality facilities should not exceed a slope of 3H:1V. Moderately undulating slopes are acceptable and can provide a more natural setting for the facility. In general, gentle side slopes improve the aesthetic attributes of the facility and enhance safety.

Water quality facilities must meet the following requirements for side slopes, fencing, and embankments:

1. If the water quality facility (wetpond, sand filter, or stormwater wetland) will hold open standing water deeper than 2 feet, fencing is required for interior slopes steeper than 3H:1V. If only sections of the slope are steeper than 3:1, barrier shrubs, such as barberry, may be used rather than fencing for sections shorter than 20 feet. Planting climbing vines at the base of a fence can enhance its aesthetic qualities.

2. If required, fencing shall be placed at or above the overflow water surface. Side slope and attendant fencing requirements are not applicable to slopes above the overflow water surface.

3. If facilities are privately owned and maintained, the fencing requirements of this manual are recommended rather than required. However, the site must still comply with any fencing requirements in other codes or regulations.

4. It is recommended that at least 25% of the facility perimeter shall have interior sides no steeper than 3H:1V, even if fenced, to minimize safety risks.

5. Interior side slopes may be retaining walls, provided that the design is prepared per City of Seattle Building Code. A fence shall be provided along the top of the wall.

6. Exterior side slopes shall not be steeper than 2H:1V unless confirmed stable by a geotechnical engineer.

7. Water quality facilities with embankments that impound water must comply with Washington State dam safety regulations (WAC 173-175). Under current regulations (as of September 1998), if the impoundment has a storage capacity (including both water and sediment storage volumes) greater than 10 acre-feet above natural ground level and a dam height of more than 6 feet, then dam safety design and review are required by the Washington Department of Ecology (Ecology). If the storage

capacity is less than 10 acre-feet above natural ground level, then the facility is exempt from Ecology review. If the dam height is less than 6 feet but capacity is greater than 10 acre-feet, then Ecology reviews on a case-by-case-basis to determine the hazard potential downstream in the event of a failure.

Intent: The requirements for slopes and fencing are intended to accomplish the following objectives:

- To prevent persons from inadvertently slipping into the pond, either by providing gentle interior side slopes (3H:1V or gentler) or by fencing or other barrier.
- To allow easy egress from the pond (gentle side slopes, safety benches, etc.) when access is not restricted by a fence or other barrier.
- To ensure interior and exterior slopes or embankments are stable and will not create a hazardous or damaging situation.

2.4 FACILITY LINERS

Water quality facilities in which water is in direct contact with the soil must be lined with either a **low permeability liner** or a **treatment liner** when the soil does not have properties which reduce the risk of groundwater contamination from stormwater runoff that may infiltrate in the facility.

Low permeability liners reduce infiltration to a very slow rate, generally less than 0.02 inches per hour (1.4 x 10^{-5} cm/s). Low permeability liners may be fashioned from compacted till, clay, geomembrane, or concrete as detailed in Section 2.4.1 (p. 19). Till liners are preferred because of their general resilience and ease of maintenance.

Treatment liners amend the soil with materials that treat stormwater before it reaches more freely draining soils. They have slow rates of infiltration, generally less than 2.4 inches per hour (1.7 x 10^{3} cm/s), but not as slow as low permeability liners. Treatment liners may use in-place native soils or imported soils. Options for this type of liner include a fine sand layer or a soil layer which has high organic content; see Section 2.4.2 (p. 20) for more option details.

Intent: In soils with high rates of infiltration, the potential exists for the transfer of pollutants from stormwater to groundwater before treatment in water quality facilities occurs. Liners are intended to reduce the likelihood that pollutants in stormwater will reach the groundwater when stormwater treatment facilities are constructed in soils with high infiltration rates.

General Design Criteria

1. Table 3 (p.9) recommends the type of liner generally best suited for use with various water quality treatment facilities.

2. Liners shall be evenly placed over the bottom and/or sides of the treatment area of the facility as indicated in Table 3. Areas above the treatment volume that are required to pass flows greater than the water quality treatment flow (or volume) need not be lined. However, the lining must be extended to the top of the interior side slope and anchored if it cannot be permanently secured by other means.

3. For low permeability liners, the following criteria apply:

   a) Where the seasonal high groundwater elevation is likely to contact a low permeability liner, liner buoyancy may be a concern. A low permeability liner shall not be used in this situation unless evaluated and recommended by a geotechnical engineer.

   b) Where grass must be planted over a low permeability liner per the facility design, a minimum of 6 inches of good topsoil or compost-amended native soil (2 inches compost tilled into 6 inches of native soil) must be placed over the liner in the area to be planted. Twelve inches is preferred.

   c) An **identification sign** should be installed indicating the facility is lined to protect water quality. In addition, the back of the sign shall include information indicating, the extent of lining, the liner material used, the liner thickness (if clay or till), and the type and distance of the marker above the liner (if a geomembrane). This information need only be readable by someone standing at arms-length from the sign.

4. If a **treatment liner** will be below the seasonal high water level, the pollutant removal performance of the liner must be evaluated by a geotechnical or groundwater specialist and found to be as protective as if the liner were above the level of the groundwater.

See Sections 2.4.1 and 2.4.2 for more specific design criteria on the various options for low permeability liners and treatment liners.

TABLE 3. LINING TYPES RECOMMENDED FOR WATER QUALITY FACILITIES

Water Quality Facility	Area to be Lined	Type of Liner Recommended
Basic biofiltration swale	Bottom and sides	Treatment liner
Wet biofiltration swale	Bottom and sides	Low permeability liner (If the swale will intercept the seasonal high groundwater table, a treatment liner is recommended.)
Continuous inflow biofiltration swale	Bottom and sides	Treatment liner
Filter strip, narrow-area filter strip	Bottom	Treatment liner
Wetpond	**First cell**: bottom and sides to water quality design water surface	Low permeability liner (If the cell will intercept the seasonal high groundwater table, a treatment liner is recommended.)
	Second cell: bottom and sides to water quality design water surface	Treatment liner
Combined detention/stormwater treatment facility	**First cell**: bottom and sides to water quality design water surface	Low permeability liner (If the cell will intercept the seasonal high groundwater table, a treatment liner is recommended.)
	Second cell: bottom and sides to water quality design water surface	Treatment liner
Wet vault	Not applicable	No liner needed
Stormwater wetland	Bottom and sides, both cells	Low permeability liner (If the facility will intercept the seasonal high groundwater table, a treatment liner is recommended.)
Sand filter	Pond sides only	Treatment liner
Sand filter vault	Not applicable	No liner needed
Linear sand filter	Not applicable if in vault	No liner needed
	Bottom and sides of presettling cell if not in vault	Low permeability or treatment liner
Leaf compost filter (in vault)	Not applicable	No liner needed

2.4.1 Design Criteria for Low Permeability Options

This section presents the design criteria for each of the following four low permeability liner options:

- Compacted till liners
- Clay liners
- Geomembrane liners
- Concrete liners.

❑ COMPACTED TILL LINERS

1. Liner thickness shall be 18 inches after compaction.

2. Soil shall be compacted to 95% minimum dry density, modified proctor method (ASTM D-1557).

3. A different depth and density sufficient to retard the infiltration rate to 2.4 x 10-5 inches per minute (1 x 10^{-6} cm/s) may also be used in lieu of Criteria 1 and 2.

4. Soil should be placed in 6 inch lifts.

5. Soils may be used that meet the following gradation:

Sieve Size	Percent Passing
6 inch	100
4 inch	90
#4	70 - 100
#200	20 - 100

❑ CLAY LINERS

1. Liner thickness shall be 12 inches.
2. Clay shall be compacted to 95% minimum dry density, modified proctor method (ASTM D-1557).
3. A different depth and density sufficient to retard the infiltration rate to 2.4 x 10^{-5} inches per minute (1 x 10^{-6} cm/s) may also be used in lieu of Criteria 1 and 2.
4. The slope of clay liners must be restricted to 3H:1V for all areas requiring soil cover; otherwise, the soil layer must be stabilized by another method so that soil slippage into the facility does not occur. Any alternative soil stabilization method must take maintenance access into consideration.
5. Where clay liners form the sides of ponds, the interior side slope must not be steeper than 3:1, irrespective of fencing. This restriction is to ensure that anyone falling into the pond may safely climb out. The same criterion is recommended for privately owned and maintained ponds.

❑ GEOMEMBRANE LINERS

1. Geomembrane liners shall be UV resistant and have a minimum thickness of 30 mils unless otherwise approved by a geotechnical engineer. A thickness of 40 mils shall be used in areas of maintenance access or where heavy machinery must be operated over the membrane.
2. Geomembranes shall be bedded according to the manufacturer's recommendations.
3. Liners shall be installed so that they can be covered with 12 inches of top dressing forming the bottom and sides of the water quality facility.[5] Top dressing shall consist of 6 inches of crushed rock covered with at least 6 inches of native soil. The rock layer is to mark the location of the liner for future maintenance operations. Other methods of designating geomembrane locations will be allowed. As an alternative to crushed rock, 12 inches of native soil may be used if orange plastic "safety fencing" or another highly-visible, continuous marker is embedded 6 inches above the membrane.
4. If possible, liners should be of a contrasting color so that maintenance workers are aware of any areas where a liner may have become exposed when maintaining the facility.
5. Geomembrane liners shall not be used on slopes steeper than 5H:1V to prevent the top dressing material from slipping. Textured liners may be used on slopes up to 3H:1V upon recommendation by a geotechnical engineer that the top dressing will be stable for all site conditions, including maintenance.

❑ CONCRETE LINERS

1. Portland cement liners are allowed irrespective of facility size, and shotcrete may be used on slopes. However, specifications must be developed by an engineer who certifies the liner against cracking or losing water retention ability under expected conditions of operation, including facility maintenance operations. Weight of maintenance equipment can be up to 80,000 pounds when fully loaded.
2. Asphalt concrete may not be used for liners due to its permeability to many organic pollutants.
3. If grass is to grown over a concrete liner, slopes must be no steeper than 5H:1V to prevent the top dressing material from slipping.

2.4.2 Design criteria for Treatment Liner Options

This section presents the design criteria for each of the following two treatment liner options:

- Sand layer
- Organic layer.

❑ SAND LAYER

1. A two-foot thick layer of sand can be used as a treatment layer beneath a water quality or detention facility if it is equivalent or finer than one of the following:
   a) The sand filter specification given in Table 16 (p. 119)

5 An exception is the linear sand filter which does not require a soil top dressing to the liner.

b) One of the following specifications:

Sieve Size	**Option 1** Minimum Percent Passing	**Option 2** Minimum Percent Passing
#4	75	75
#40	25	50
#200	5	2

2. The sand must be certified as meeting one of the above criteria. Such certification can be provided by the sand supplier or by a soils testing laboratory.
3. In-place soils may be substituted for sand if they meet one of the above criteria as demonstrated by testing one soil sample per 1,000 square feet of facility area. Each sample shall be a composite of subsamples taken throughout the depth of the treatment layer.

❑ ORGANIC SOIL LAYER

1. A two-foot thick layer of soil with a minimum organic content of 5%[6] *and* a minimum cation exchange capacity (CEC) of 5 milliequivalents/100 grams can be used as a treatment layer beneath a water quality or detention facility.

   If a thicker layer of treatment soil is available, the organic content and CEC requirements can be reduced by 1/2 unit for each additional foot of soil thickness provided.

   Example

   If the treatment liner will be 4 feet thick, 2 feet more than the required 2 feet, the organic content may be reduced by 1/2 x 2 = 1 unit. The organic content could then be 4%, and the CEC requirement could be 4 milliequivalents/100 grams and still meet the groundwater protection criteria.

2. **Organic content** shall be measured on a dry weight basis using ASTM D2974.
3. **Cation exchange capacity** (CEC) shall be tested using EPA laboratory method 9081.
4. **Certification** by a soils testing laboratory that imported soil meets the organic content and CEC criteria above shall be provided to the DCLU inspector.
5. **Animal manure** used in treatment soil layers must be sterilized because of potential for bacterial contamination of the groundwater.
6. To demonstrate that in-place soils meet Requirement 1 above, one **sample** per 1,000 square feet of facility area shall be tested. Each sample shall be a composite of subsamples taken throughout the depth of the treatment layer (usually two to six feet below the expected facility invert).
7. If a reduction in the organic content and CEC criteria is sought because the treatment layer is thicker than 2 feet, soil tests must represent the entire treatment layer.

[6] Note: The King County *Surface Water Design Manual* (1998) allows a different minimum organic content.

8. Compost used in treatment soil layers shall meet City of Seattle specifications for **decomposed organic mulch** (City of Seattle *Standard Specifications for Road, Bridge and Municipal Construction,* 2000 Edition)

2.5 FLOW SPLITTER DESIGNS

Most water quality facilities can be designed as **flow-through, or on-line, systems** with flows above the water quality design flow or volume simply passing through the facility untreated. However, it is sometimes desirable to restrict flows to water quality treatment facilities and bypass the remaining higher flows around them **(off-line facilities)**. This can be accomplished by **splitting flows** in excess of the water quality design flow upstream of the facility and diverting higher flows to a bypass pipe or channel. The bypass typically enters a detention facility or the downstream receiving drainage system, depending on flow control requirements. In most cases, it is a designer's choice whether stormwater treatment facilities are designed as on-line or off-line; an exception is oil/water separators, which must be designed off-line.

2.5.1 Method of Analysis

A crucial factor in designing flow splitters is to ensure that low flows are delivered to the treatment facility up to the **water quality design flow** (see Section 2.1, p. 11). Above this rate, additional flows are diverted to the bypass system with minimal increase in head at the flow splitter structure to avoid surcharging the water quality facility under high flow conditions.

Flow splitters are typically catch basins or vaults with concrete baffles. In place of baffles, the splitter mechanism may be a half tee section with a solid top and an orifice in the bottom of the tee section. A full tee option may also be used (see "Design Criteria" below). Two possible design options for flow splitters are shown in Figure 2 and Figure 3. Other equivalent designs that achieve the result of splitting low flows, up to the water quality design flow, into the stormwater treatment facility and divert higher flows around the facility are also acceptable.

2.5.2 Design Criteria

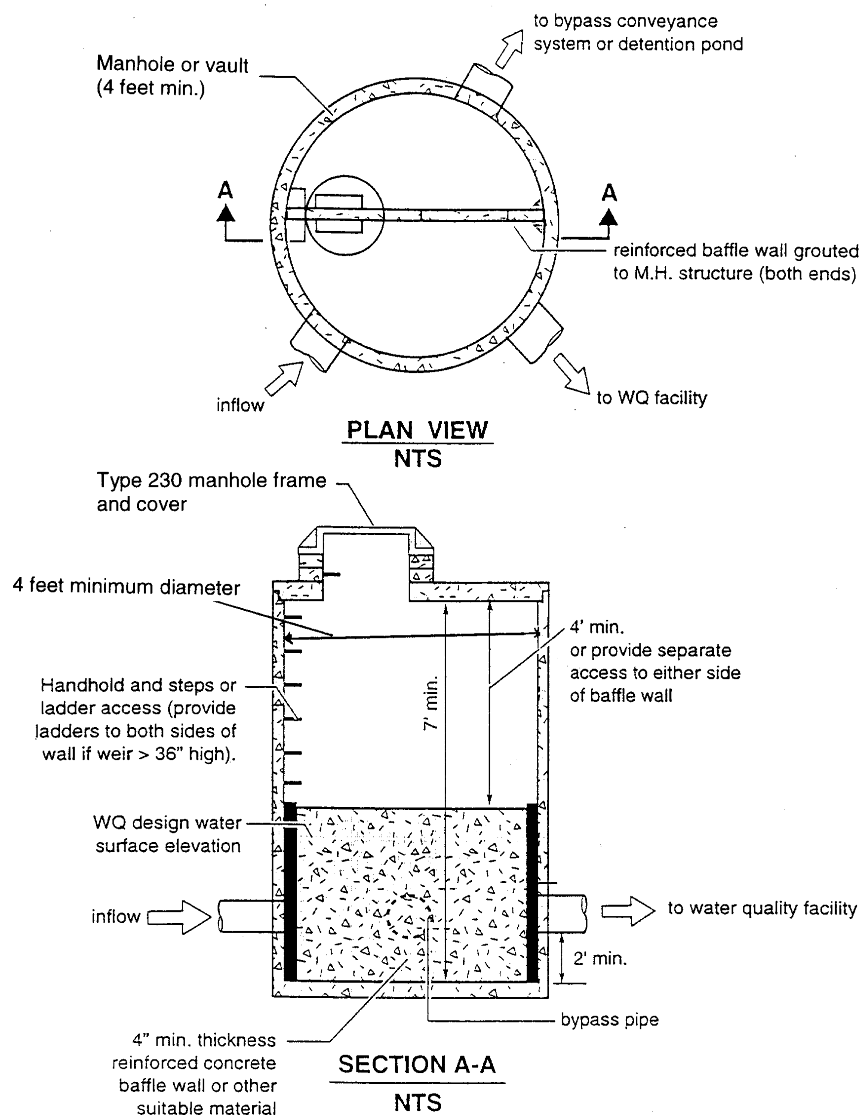
General

1. A flow splitter shall be designed to deliver the required **water quality design flow rate** specified in Section 2.1 (p. 11) to the stormwater treatment facility. The sand filter is sized based on volume using the water quality design flow rate to design the splitter.
2. The **top of the weir** shall be located at the water surface for the design flow. Remaining flows enter the bypass line.
3. The **maximum head** shall be minimized for flow in excess of the water quality design flow. Specifically, flow to the stormwater treatment facility at the 100-year water surface shall not increase the water quality design flow by more than 10%.
4. Either design shown in Figure 2 (p. 25) or Figure 2 (p. 26) may be used. Equivalent designs are also acceptable.
5. Special applications, such as roads, may require the use of a **modified flow splitter**. The baffle wall may be fitted with a notch and adjustable weir plate to proportion runoff volumes other than high flows.
6. For ponding facilities, backwater effects must be included in designing the height of the standpipe in the catch basin.
7. Ladder or step and handhold access shall be provided. If the weir wall is higher than 36 inches, two ladders, one to either side of the wall, are required.

Material Requirements

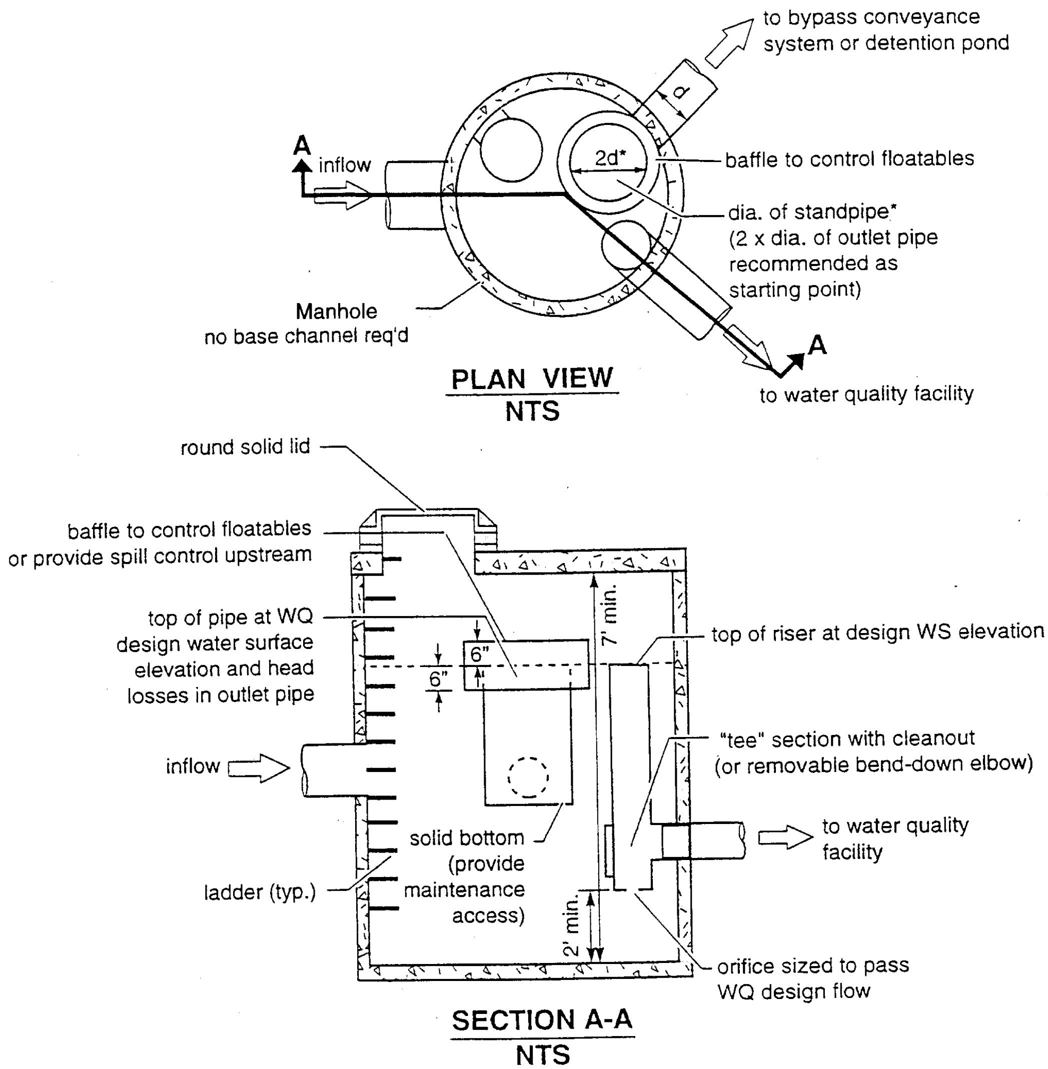
1. The **splitter baffle** shall be installed in a manhole (minimum 4 feet diameter) or vault.
2. The **baffle wall** shall be made of reinforced concrete or another suitable material resistant to corrosion, and have a minimum 4-inch thickness. The minimum clearance between the top of the baffle wall and the bottom of the catch basin cover shall be 4 feet; otherwise, dual access points shall be provided.
3. All **metal parts** shall be corrosion resistant. Examples of preferred materials include aluminum, stainless steel, and plastic. Zinc and galvanized materials are discouraged because of aquatic toxicity. Painting metal parts shall not be allowed because of poor longevity.

FIGURE 2. FLOW SPLITTER, OPTION A



Note: The water quality discharge pipe may require an orifice plate be installed on the outlet to control the height of the design water surface (weir height). The design water surface should be set to provide a minimun headwater/diameter ratio of 2.0 on the outlet pipe.

FIGURE 3. FLOW SPLITTER OPTION B



* **NOTE:** Diameter (d) of standpipe should be large enough to minimize head above WQ design WS and to keep WQ design flows from increasing more than 10% during 100-year flows.

2.6 FLOW SPREADING OPTIONS

Flow spreaders function to uniformly spread flows across the inflow portion of water quality facilities (e.g., sand filter, biofiltration swale, or filter strip). There are five flow spreader options presented in this section:

- Anchored plate (Option A)
- Concrete sump box (Option B)
- Notched curb spreader (Option C)
- Through-curb ports (Option D)
- Interrupted curbing (Option E).

Options A through C can be used for spreading flows that are concentrated. Any one of these options can be used when spreading is required by the facility design criteria. Options A through C can also be used for unconcentrated flows, and in some cases must be used, such as to correct for moderate grade changes along a filter strip.

Options D and E are only for flows that are already unconcentrated and enter a filter strip or continuous inflow biofiltration swale. Other flow spreader options are possible with approval from DCLU.

2.6.1 Design Criteria

General Design Criteria

1. Where flow enters the flow spreader through a pipe, it is recommended that the **pipe be submerged** to the extent practical to dissipate energy as much as possible.
2. For **higher velocity inflows** (greater than 5 cfs for the 100-year storm), a catch basin should be positioned in the spreader, and the inflow pipe should enter the catch basin with flows exiting through the top grate. The top of the grate should be lower than the level spreader plate, or if a notched spreader is used, lower than the bottom of the v-notches.
3. Table 4 provides general guidance for rock protection at outfalls.

❑ OPTION A ¾ ANCHORED PLATE (FIGURE 4)

1. An anchored plate flow spreader shall be **preceded by a sump** having a minimum depth of 8 inches and minimum width of 24 inches. If not otherwise stabilized, the sump area shall be lined to reduce erosion and to provide energy dissipation.
2. The top surface of the flow spreader plate **shall be level**, projecting a minimum of 2 inches above the ground surface of the water quality facility, or **v-notched** with notches 6 to 10 inches on center and 1 to 6 inches deep (use shallower notches with closer spacing). Alternative designs are allowed.
3. A flow spreader plate shall extend horizontally beyond the bottom width of the facility to prevent water from eroding the side slope. The **horizontal extent** should be such that the bank is protected for all flows up to the 100-year flow or the maximum flow that will enter the water quality facility.
4. Flow spreader plates shall be **securely fixed in place**.

5. Flow spreader plates may be made of either **wood, metal, fiberglass reinforced plastic, or other durable material**. If wood, pressure treated 4 by 10-inch lumber or landscape timbers are acceptable.
6. **Anchor posts** shall be 4-inch square concrete, tubular stainless steel, or other material resistant to decay.

❑ OPTION B ¾ CONCRETE SUMP BOX (FIGURE 5)

1. The **wall of the downstream side** of a rectangular concrete sump box shall extend a minimum of 2 inches above the treatment bed. This serves as a weir to spread the flows uniformly across the bed.
2. The **downstream wall** of a sump box shall have "wing walls" at both ends. **Side walls and returns** shall be slightly higher than the weir so that erosion of the side slope is minimized.
3. **Concrete** for a sump box can be either cast-in-place or precast, but the bottom of the sump shall be reinforced with wire mesh for cast-in-place sumps.
4. Sump boxes shall be placed over bases that consists of 4 inches of crushed rock, 5/8-inch minus to help assure the sump remains level.

❑ OPTION C ¾ NOTCHED CURB SPREADER (FIGURE 6)

Notched curb spreader sections shall be made of extruded concrete laid side by side and level. Typically five "teeth" per four-foot section provide good spacing. The space between adjacent "teeth" forms a v-notch.

❑ OPTION D ¾ THROUGH-CURB PORTS (FIGURE 7)

Unconcentrated flows from paved areas entering filter strips or continuous inflow biofiltration swales can use curb ports or interrupted curbs (Option E) to allow flows to enter the strip or swale. Curb ports use fabricated openings that allow concrete curbing to be poured or extruded while still providing an opening through the curb to admit water to the water quality facility.

Openings in the curb shall be at regular intervals but at least every 6 feet (minimum). The width of each curb port opening shall be a minimum of 11 inches. Approximately 15% or more of the curb section length should be in open ports, and no port should discharge more than about 10% of the flow.

❑ OPTION E ¾ INTERRUPTED CURB (NO FIGURE)

Interrupted curbs are sections of curb placed to have gaps spaced at regular intervals along the total width (or length, depending on facility) of the treatment area. At a minimum, **gaps** shall be every 6 feet to allow distribution of flows into the treatment facility before they become too concentrated. The opening shall be a minimum of 11 inches. As a general rule, no opening should discharge more than 10% of the overall flow entering the facility.

TABLE 4. ROCK PROTECTION AT OUTFALLS						
DISCHARGE VELOCITY AT DESIGN FLOW (FPS)		REQUIRED PROTECTION				
GREATER THAN	LESS THAN OR EQUAL TO	MINIMUM DIMENSIONS				
		TYPE	THICKNESS	WIDTH	LENGTH	HEIGHT
0	5	ROCK LINING(1)	1 FOOT	DIAMETER + 6 FEET	8 FEET OR 4 X DIAMETER, WHICHEVER IS GREATER	CROWN + 1 FOOT
5	10	RIPRAP(2)	2 FEET	DIAMETER + 6 FEET OR 3 X DIAMETER, WHICHEVER IS GREATER	12 FEET OR 4 X DIAMETER, WHICHEVER IS GREATER	CROWN + 1 FOOT
10	20	GABION OUTFALL	AS REQUIRED	AS REQUIRED	AS REQUIRED	CROWN + 1 FOOT
20	N/A	ENGINEERED ENERGY DISSIPATER REQUIRED				

(1) **ROCK LINING** SHALL BE QUARRY SPALLS WITH GRADATION AS FOLLOWS:

PASSING 8-INCH SQUARE SIEVE:	100%
PASSING 3-INCH SQUARE SIEVE:	40 TO 60% MAXIMUM
PASSING 3/4-INCH SQUARE SIEVE:	0 TO 10% MAXIMUM

(2) **RIPRAP** SHALL BE REASONABLY WELL GRADED WITH GRADATION AS FOLLOWS:

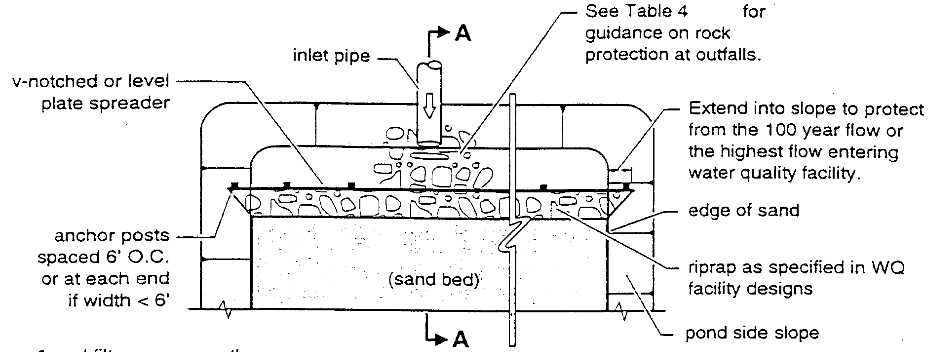
MAXIMUM STONE SIZE:	24 INCHES (NOMINAL DIAMETER)
MEDIAN STONE SIZE:	16 INCHES
MINIMUM STONE SIZE:	4 INCHES

NOTE: RIPRAP SIZING GOVERNED BY SIDE SLOPES ON OUTLET CHANNEL IS ASSUMED TO BE APPROXIMATELY 3:1

(SOURCE: KING COUNTY SURFACE WATER DESIGN MANUAL, 1998. TABLE 4.2.2.A)

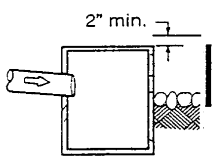
FIGURE 4. FLOW SPREADER OPTION A: ANCHORED PLATE

Example of anchored plate used with a sand filter* (may also be used with other water quality facilities).

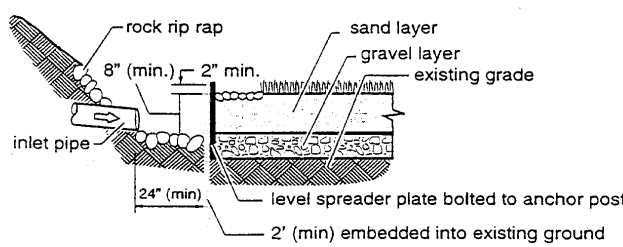


*sand filter may use other spreading options

PLAN VIEW
NTS



Alternative Design
Catch basin recommended for higher flow situations (generally for inflow velocities of 5 fps or greater for 100 year storm).



SECTION A-A
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FIGURE 5. FLOW SPREADER OPTION B: CONCRETE SUMP BOX

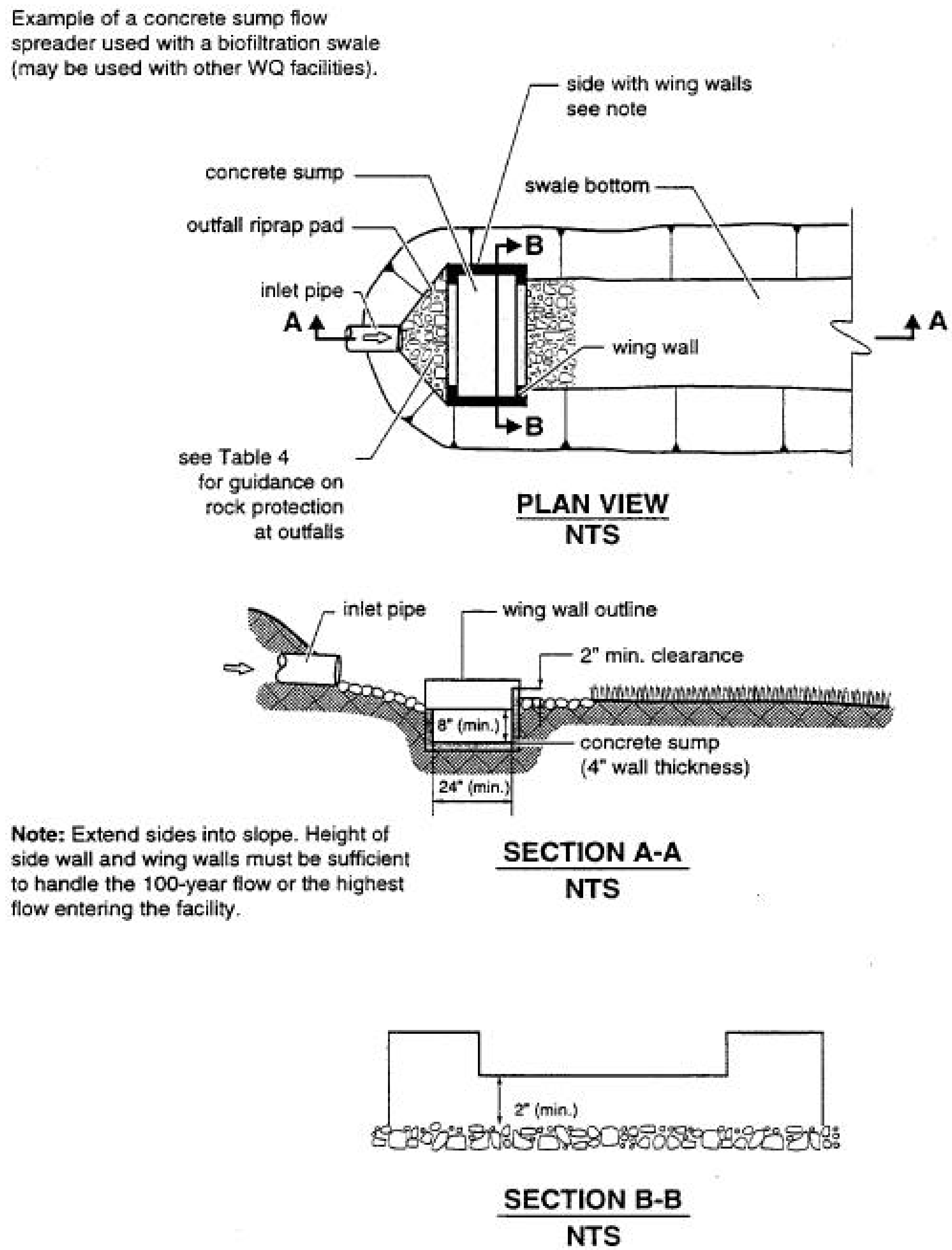
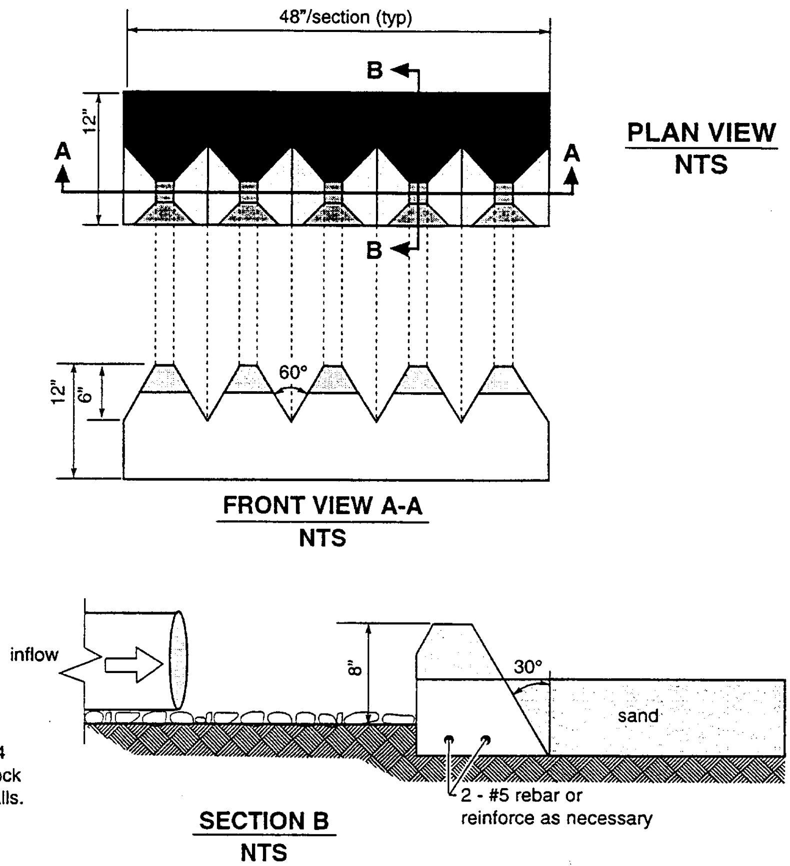
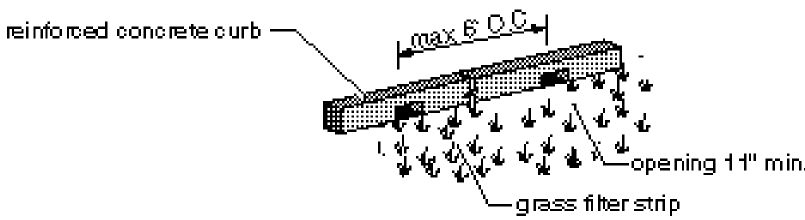


FIGURE 6. FLOW SPREADER OPTION C: NOTCHED CURB SPREADER



Note: See Table 4 for guidance on rock protection at outfalls.

FIGURE 7. FLOW SPREADER OPTION D: THROUGH-CURB PORT



CURB PORT
NTS

3 BIOFILTRATION FACILITY DESIGNS

This section presents the methods, details of analysis, and design criteria for biofiltration swales and filter strips. Included in this section are the following specific facility designs:

- Basic Biofiltration Swales, Section 3.1
- Wet Biofiltration Swales, Section 3.2
- Continuous Inflow Biofiltration Swales, Section 3.3
- Basic Filter Strips, Section 3.4
- Narrow Area Filter Strips, Section 3.5

The information presented for each facility is organized into the following two categories:

1. **Methods of Analysis:** Contains a step-by-step procedure for designing and sizing each facility. Information presented in the procedure is based on available literature, but clarified or modified where deficiencies were identified.[7]
2. **Design Criteria:** Contains the details, specifications, and material requirements for each facility.

3.1 BASIC BIOFILTRATION SWALES

A *biofiltration swale* is an open, gently sloped, vegetated channel designed for treatment of stormwater (see the details in Figure 8 through Figure 12 beginning on page 49). The primary pollutant removal mechanisms are filtration by grass blades or other approved vegetation, which enhance sedimentation, and trapping and adhesion of pollutants to the grass and thatch. Biofiltration swales generally do not remove dissolved pollutants effectively.

Applications and Limitations

A biofiltration swale is designed so that water will flow evenly across the entire width of a densely-vegetated area. A swale can be designed for both treatment and conveyance of onsite stormwater flow. This combined use can reduce development costs by eliminating the need for separate conveyance systems.

Biofiltration swales are best applied on a relatively small scale (generally less than five acres of impervious surface). They work well along roadways, driveways, and parking lots. Swales are more costly to apply in situations where the swale channel would be deep; in deep swales, self-shading can inhibit the necessary grass growth, resulting in poor pollutant removal performance. Some specific considerations for biofiltration swale applications are as follows:

- A biofiltration swale using grass **should not be located in a mostly shaded area**. For healthy grass growth, a swale should receive a minimum of 6 hours of sunlight daily during the summer months throughout the length of the swale. Alternative vegetation should be considered if conditions for grass growth cannot be met.
- To maintain healthy grass growth, a **swale must dry between storms**. It should not receive continuous base flows (such as seepage from a hill slope throughout the winter) or be located in a high groundwater area, because saturated soil conditions will kill grass.

[7] Such modifications are often based on computer modeling using the King County Runoff Time Series (KCRTS) model. Occasionally they were based on bench-scale studies.

If these conditions are likely to occur, design options are given under "Design Criteria" (p. 39), or the wet biofiltration swale design can be used (see Section 3.2, p. 52, for details).

- Stormwater runoff carrying **high concentrations of oil and grease impairs the treatment capability** of a swale. Oil control options given in Section 6 (p. 145) should be applied in these situations.
- **Modifying an existing drainage ditch** to create an engineered biofiltration swale may be difficult due to physical constraints and because ditches often serve as conveyance for flows from larger offsite areas. In these situations, high-flow bypass systems are frequently required.
- **Utilities** may be located in swale side slopes above the water quality design depth. However, the repair or placement of utilities in swale side slopes requires aggressive implementation of erosion control practices to prevent soil and sediment from reaching the treatment area of the swale.

Note: Consult Table 1 on page 9 for guidance on which type of biofiltration swale (basic, wet or continuous inflow) to use for a given set of site characteristics.

3.1.1 Methods of Analysis

Biofiltration swale sizing is based on several variables, including the peak water quality design flow, longitudinal slope, vegetation height, bottom width, side slope, required hydraulic residence time (i.e., the time required for flow to travel the full length of the swale), and design flow depth.

Step 1: Calculate design flows. The swale design is based on the water quality design flow Q_{wq} (see Section 2.1 for a definition of water quality design flow). These flows must be estimated using the hydrologic analysis procedures described in detail in Appendix A. If the swale is located downstream of an onsite detention facility, the swale design flow should correspond to the release rate from the detention facility.

Step 2: Calculate swale bottom width. The swale bottom width is calculated based on Manning's equation for open-channel flow. This equation can be used to calculate discharges as follows:

$$Q = \frac{1.49}{n} AR^{0.67} s^{0.5} \qquad (3\text{-}1)$$

where
Q = flow rate (cfs)
n = Manning's roughness coefficient (unitless)
A = cross-sectional area of flow (sf)
R = hydraulic radius (ft) = area divided by wetted perimeter
s = longitudinal slope (ft/ft)

For shallow flow depths in swales, channel side slopes are ignored in the calculation of bottom width. Use the following equation (a simplified form of Manning's formula) to estimate the swale bottom width:

$$b \quad = \quad \frac{Q_{wq} n_{wq}}{1.49 y^{1.67} s^{0.5}} \tag{3-2}$$

where b = bottom width of swale (ft)
Q_{wq} = water quality design flow (cfs)
n_{wq} = Manning's roughness coefficient for shallow flow conditions = 0.20 (unitless)
y = design flow depth (ft)
s = longitudinal slope (along direction of flow) (ft/ft)

See "Water Depth and Base Flow" (p. 40) to determine the allowable design water depth. Proceed to Step 3 if the bottom width is calculated to be between 2 and 10 feet.

A minimum 2-foot bottom width is required. Therefore, if the calculated bottom width is less than 2 feet, increase the width to 2 feet and recalculate the design flow depth y using Equation (3-1) as follows:

$$Y \quad = \quad \left(\frac{Q_{wq} n_{wq}}{1.49 s^{0.5} b} \right)^{3/5} \tag{3-3}$$

where Q_{wq}, n_{wq}, and s are the same values as used in Equation (3-2), but b = 2 feet.

The maximum bottom width is 10 feet; therefore if the calculated bottom width exceeds 10 feet, then one of the following steps is necessary to reduce the design bottom width:

- Increase the longitudinal slope s to a maximum of 6 feet in 100 feet (0.06 feet per foot).
- Increase the design flow depth y to a maximum of 4 inches (0.333 feet).
- Reduce the design flow rate by rearranging the swale location with respect to detention facilities; a swale located downstream of a detention facility may have a lower flow rate due to flow attenuation in the detention facility. However, if a swale is located downstream of a detention facility, and it is located in till soils, then the swale must be designed as a wet biofiltration swale (see Section 3.2, p. 52).
- Place a divider lengthwise along the swale bottom (cross-section) at least three-quarters of the swale length (beginning at the inlet), without compromising the design flow depth and swale lateral slope requirements. See "Design Criteria" (p. 39) for swale divider requirements. A flow spreader must be provided at the inlet to evenly divide flows into each half of the swale cross-section. See Section 0 (p. 27) for details on flow spreaders.

Step 3: Determine design flow velocity. To calculate the design flow velocity through the swale, use the flow continuity equation:

$$V_{wq} = \frac{Q_{wq}}{A_{wq}} \tag{3-4}$$

where V_{wq} = design flow velocity (fps)
A_{wq} = $by + Zy^2$ = cross-sectional area (sf) of flow at design depth
Z = side slope length per unit height (e.g., Z = 3 if side slopes are 3H:1V)

If the design flow velocity exceeds 1 foot per second, go back to Step 2 and modify one or more of the design parameters (longitudinal slope, bottom width, or flow depth) to reduce the design flow velocity to 1 foot per second or less. If the design flow velocity is calculated to be less than 1 foot per second, proceed to Step 4. *Note: It is desirable to have the design velocity as low as possible, both to improve treatment effectiveness and to reduce swale length requirements.*

Step 4: Calculate swale length. Use the following equation to determine the necessary swale length to achieve a hydraulic residence time of at least 9 minutes (540 seconds):

$$L = 540V_{wq} \qquad (3\text{-}5)$$

where L = minimum allowable swale length (ft)
V_{wq} = design flow velocity (fps)

The minimum swale length is 100 feet; therefore, if the swale length is calculated to be less than 100 feet, increase the length to a minimum of 100 feet, leaving the bottom width unchanged. If a larger swale could be fitted on the site, consider using a greater length to increase the hydraulic residence time and improve the swale's pollutant removal capability. If the calculated length is too long for the site, or if it would cause layout problems, such as encroachment into shaded areas, proceed to Step 5 to further modify the layout. If the swale length can be accommodated on the site, proceed to Step 6.

Step 5: Adjust swale layout to fit on site. If the swale length calculated in Step 4 is too long for the site, the length can be reduced (to a minimum of 100 feet) by increasing the bottom width up to a maximum of 16 feet. However, the length cannot be increased in order to reduce the bottom width because Manning's depth-velocity-flow rate relationships would not be preserved. If the bottom width is increased to greater than 10 feet, a low dividing berm is needed to split the swale cross-section in half. Note that a contiguous swale is not required to achieve the 100 feet minimum length; swale segments can be connected using a combination of culverts and flow dissipaters.

Length can be adjusted by finding the top area of the swale and providing an equivalent top area with the adjusted dimensions.

a) Calculate the swale treatment top area based on the swale length calculated in Step 4:

$$A_{top} = (b_i + b_{slope})\, L_i \qquad (3\text{-}6)$$

where A_{top} = top area (sf) at the design treatment depth
b_i = bottom width (ft) calculated in Step 2
b_{slope} = the additional top width (ft) above the side slope for the design water depth (for 3:1 side slopes and a 4-inch water depth, b_{slope} = 2 feet)
L_i = initial length (ft) calculated in Step 4.

b) Use the swale top area and a reduced swale length L_f to increase the bottom width, using the following equation:

$$L_f = \frac{A_{top}}{(b_f + b_{slope})} \qquad (3\text{-}7)$$

where L_f = reduced swale length (ft)
b_f = increased bottom width (ft).

c) Recalculate V_{wq} according to Step 3 using the revised cross-sectional area A_{wq} based on the increased bottom width b_f. Revise the design as necessary if the design flow velocity exceeds 1 foot per second.

3.1.2 Design Criteria

An effective biofiltration swale achieves uniform sheet flow over and through a densely vegetated area for a period of several minutes. Figure 8 (p. 49) shows a typical biofiltration swale schematic. Basic design requirements for achieving proper flow conditions through a biofiltration swale are described below.

Swale Geometry

1. Swale **bottom width** shall be between 2 and 16 feet.[8]
   a) **Minimum bottom width** is 2 feet to allow for ease of mowing.
   b) If the bottom width exceeds 10 feet, a length-wise divider shall be provided. The divider shall extend from the flow spreader at the inlet for at least three-quarters of the swale length.
   c) **Maximum bottom width** is 16 feet, excluding the width of the divider.

   Note: Multiple swales may be placed side by side provided the flow to each swale is split at the inlet and spread separately for each swale. Adjacent swales may be separated with a vertical wall, but a low berm is preferred for easier maintenance and better landscape integration.
2. The **longitudinal slope** (along the direction of flow) shall be no less than 2% and should be no greater than 6%.[9]
   a) If the longitudinal slope exceeds 6%, **check dams** with vertical drops of 12 inches or less shall be provided to achieve a bottom slope of 6% or less between the drop sections.
3. The swale shall be **flat** in cross-section (perpendicular to the flow direction) to promote even flow across the whole width of the swale.
4. The **minimum swale length** shall be 100 feet; no maximum length is set.
5. The **swale treatment area** (below the water quality design water depth) shall be trapezoidal in cross-section. If trapezoidal, **side slopes within the treatment area** should be 3H:1V or flatter whenever possible, but not steeper than 2H:1V.
6. **Side slope sections above the treatment area** may be steeper than 3H:1V, subject to the following provisions:

[8] Experience with biofiltration swales shows that when the width exceeds about 10 feet it is difficult to keep the water from forming low-flow channels. It is also difficult to construct the bottom level and without sloping to one side. Biofilters are best constructed by leveling the bottom after excavating, and after the soil is amended. A single-width pass with a front-end loader produces a better result than a multiple-width pass.

[9] Note: The King County *Surface Water Design Manual* (1998) allows for a longitudinal slope of less than 2%.

a) If there is an interior side slope between 1H:1V and 2H:1V outside the treatment area, the slope shall be reinforced with **erosion control netting or matting** during construction.

b) Any interior slope steeper than 1H:1V shall be constructed as a **rockery or structural retaining wall**[10] to prevent the swale slope from sloughing. To ensure that adequate sunlight reaches the swale bottom, **only one wall can be taller than 2 feet.** If possible, the higher wall should be on the northern or eastern side of the swale to maximize the amount of light reaching the swale bottom.

7. **Curved swales** are encouraged for aesthetic reasons, but curves must be gentle to prevent erosion and allow for vehicle access to remove sediment. Criteria for maintenance access road curves should also be applied for swale curves.

Water Depth and Base Flow

1. A swale that will be **frequently mowed**, as in commercial or landscaped areas, shall have a **design water depth** of no more than 2 inches (0.17 feet) under the water quality design flow conditions.
2. A swale that will **not be frequently mowed**, such as along roadsides or in rural areas, shall have a **design water depth** of no more than 4 inches (0.33 feet) under the water quality design flow conditions.
3. If a swale is located **downstream of a detention**, and it is located in till soils, then the swale must be designed as a **wet biofiltration swale** (see Section 3.2, p. 52).
4. If a swale will receive **base flows** because of seeps and springs on site, then either a low-flow drain shall be provided or a wet biofiltration swale shall be used. *Low-flow drains* are narrow surface drains filled with pea gravel that run lengthwise through the swale to bleed off base flows; they should not be confused with underdrains. In general, base flows less than 0.01 cfs per acre can be handled with a low-flow drain. If flows are likely to be in excess of this level, a wet biofiltration swale should be used.
5. If a **low-flow drain** is used, it shall extend the entire length of the swale. The drain shall be a minimum of 6 inches deep, and its width shall be no greater than 5 percent of the calculated swale bottom width; the width of the drain shall be in addition to the required bottom width. If an anchored plate or concrete sump is used for flow spreading at the swale inlet, the plate or sump wall shall have a v-notch (maximum top width = 5% of swale width) or holes to allow preferential exit of low flows into the drain. See Figure 11 (p. 51) for low-flow drain specifications and details.

Flow Velocity, Energy Dissipation, and Flow Spreading

1. The **maximum flow velocity** through the swale under the water quality design flow conditions shall not exceed 1.0 foot per second.
2. The **maximum flow velocity** through the swale under the peak 100-year flow conditions shall not exceed 3.0 feet per second.
3. A **flow spreader** shall be used at the inlet of a swale to dissipate energy and evenly spread runoff as sheet flow over the swale bottom. Flow spreaders are recommended but not required at mid-length. For details on various types of flow spreaders, see Section 0 (p. 27).

[10] Soil bioengineering techniques may be used as an alternative to a rockery or structural retaining wall.

4. If **check dams** are used to reduce the longitudinal slope of the swale, a **flow spreader** shall be provided at the toe of each vertical drop. The spreader must span the width of the swale. An **energy dissipater** should also be provided if flows leaving the spreader could be erosive.
5. If a swale **discharges flows to a slope** rather than to a piped system or confined channel, an **energy dissipater** shall be provided at the swale outlet. This requirement also applies to discharges from swale underdrains. The outlet energy dissipater can be a riprap pad sized according to the specifications described in Table 4 for conveyance system outfalls.

Underdrains

If underdrains are required by Criterion 2 under "Swale Geometry" (p.39), they must meet the following criteria:

1. Underdrains must be made of **PVC perforated pipe**, laid parallel to the swale bottom and backfilled and bedded as shown in Figure 10 (p. 50).
2. The underdrain pipe should be 6 inches or greater in **diameter**. (Six inches is the smallest diameter pipe that can be cleaned without damage to the pipe.)
3. Six inches of clean **drain rock** (5/8-inch minus) must be above the top of the pipe.
4. The drain rock must be wrapped in **geotextile**. Geotextile requirements are summarized in Table 5 below.
5. The underdrain **must infiltrate** into the subsurface **or drain freely** to an acceptable discharge point.

TABLE 5. GEOTEXTILE MATERIAL MINIMUM REQUIREMENTS		
Geotextile Property[11]	**Value (Woven/Nonwoven)**	**Test Method**
Grab Tensile Strength, min, in machine and x-machine direction	180 lbs./115 lbs. (min)	ASTM D4632
Grab Failure Strain, in machine and x-machine direction	< 50%/≥ 50%	ASTM D4632
Seam Breaking Strength	160 lbs./100 lbs. (min)	ASTM D4632
Puncture Resistance	67 lbs./40 lbs. (min)	ASTM D4833
Tear Strength, min. in machine and x-machine direction	67 lbs./40 lbs. (min)	ASTM D4533
AOS (sieve size)	#60 – #70	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355
Permeability	0.2 cm/sec (min)	ASTM D4491
Note: If construction conditions dictate use of a more durable geotextile material to prevent punctures or tearing during installation, a heavier fabric should be used.		

Swale Divider

1. If a swale divider is used (such as when swale bottom widths are greater than 10 feet), the divider should be constructed of a **firm material** that will resist weathering and not erode, such as treated lumber, concrete, plastic, or compacted soil seeded with grass. Selection of divider material should take into consideration swale maintenance, especially mowing.
2. The divider shall have a **minimum height** of one inch higher than the water quality design water depth.
3. **Earthen berms** should be no steeper than 2H:1V.
4. Materials other than earth (e.g. treated lumber, recycled plastic lumber, concrete, etc.) shall be embedded to a depth sufficient to be stable.

Access

1. **Wheel strips** made of modular grid pavement may be built into the swale bottom for maintenance vehicle access instead of an access road. The subgrade for the strips must be engineered to support a vehicle weight of 16,000 pounds and installed according to the manufacturer's recommendations on firm native soil or structural fill, not on the amended topsoil. Each strip shall be 18 inches wide and spaced as shown in Figure 12 (p. 51). The strip lattice should be filled or covered with native soil (no amendments required)

[11] All geotextile properties are minimum average roll values (i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table). Values for tensile strength, failure strain, seam breaking strength, puncture resistance, and tear strength are from Washington State Department of Transportation, Standard Specifications: 2000. Section 9-33, and are not contained in the King County *Surface Water Design Manual* (1998).

and overseeded with grass. If a low-flow drain is also needed (see "Water Depth and Base Flow" on page 40), a portion of the wheel strip may be filled with pea gravel as appropriate to form the drain. Wheel strips shall not be counted as treatment area; therefore, the swale bottom width must be increased accordingly.

Soil Amendment

1. Two inches (minimum) of **well-rotted compost** shall be tilled into the entire swale treatment area to amend the topsoil unless the soil already has an organic content of 5%[12] or greater. This applies to both till soils as well as sandy soils. In very coarse soils (gravel or courser), **top soil** must be imported and amended to the required organic content.
   a) Compost must be tilled into the underlying native soil to a depth of 6 inches to prevent the compost from being washed out and to avoid creating a defined layer of different soil types that can prevent downward percolation of water.
   b) Compost shall not contain any sawdust, straw, green or under-composted organic matter, or toxic or otherwise harmful materials.
   c) Compost should not contain unsterilized manure because it can leach fecal coliform bacteria into receiving waters.
2. **Soil or sod** with a clay content of greater than 10% should be avoided. If there is concern for contamination of the underlying groundwater, the swale bottom should be lined with a treatment liner to prevent groundwater contamination. See Section 2.4 (p. 17) for details on treatment liner options.

Planting Requirements

1. Grass shall be established throughout the entire treatment area of the swale subject to the following provisions:
   a) **Seeding** is best performed in spring (mid-March to June) or fall (late September to October). For summer seeding, sprinkler systems or other measures for watering the grass seed must be provided.
   b) Seed may be applied via **hydroseeding** or broadcast application.
2. **Irrigation** is required during the first summer following installation if seeding occurs in spring or summer. Swales seeded in the fall may not need irrigation. Swale treatment areas are subject to both dry and wet conditions, as well as accumulation of sediment and debris. A mixture of dry-area and wet-area grass species that can continue to grow through silt deposits is most effective. Two acceptable **grass seed mixes** are listed in Table 6 (p. 44). The mixes should be applied throughout the swale in the treatment area at a rate of 80 pounds per acre. As an alternative to these mixes, a horticultural or erosion control specialist may develop a seed specification tailored to the site. Table 7 (p. 45) lists grasses or other plants particularly tolerant of wet conditions. Some of these seed types, however, may not be commercially available.
3. A newly constructed swale shall be **protected from stormwater flows until grass has been established**. This may be done by diverting flows or by covering the swale bottom with clear plastic until the grass is well rooted.

[12] Note: The King County *Surface Water Design Manual* (1998) allows a different minimum organic content.

4. **Above the design treatment elevation**, either a typical lawn seed mix or landscape plants may be used. However, for swales also used to convey high flows, consideration should be given to the soil binding capacity of the vegetation. Acceptable grasses and groundcovers are presented in Table 8 (p. 46). Plant material other than that given in the table may be used if the plants selected will not spread into the swale treatment area. Ivy may not be used because of its tendency to spread. Native plant species (e.g., kinnikinnick) are preferred.

   Note: These recommendations are for the King County area. If these designs are used in other areas, local knowledge should be used to tailor these recommendations to local conditions.

5. **Sod** may be used as a temporary cover during the wet season, but sodded areas must be reseeded with a suitable grass seed mix as soon as the weather is conducive to seed germination, unless the sod is grown from a seed mix suitable for the wetter conditions of a biofiltration swale. Sod must be removed or rototilled into the underlying soil before reseeding. Criteria #1 and 2 above for seeding should then be followed.

TABLE 6. GRASS SEED MIXES SUITABLE FOR BIOFILTRATION SWALE TREATMENT AREAS

Mix 1		**Mix 2**	
75-80 percent	Tall or Meadow Fescue	60-70 percent	Tall Fescue
10-15 percent	Seaside Creeping Bentgrass or Colonial Bentgrass	10-15 percent	Seaside Creeping Bentgrass or Colonial Bentgrass
5-10 percent	Redtop	10-15 percent	Meadow Foxtail
		6-10 percent	Alsike Clover
		1-5 percent	Marshfield Big Trefoil
		1-6 percent	Redtop

Note: All percentages are by weight.

TABLE 7. FINELY-TEXTURED PLANTS TOLERANT OF FREQUENT SATURATED SOIL CONDITIONS OR STANDING WATER			
Grasses		**Wetland Plants**	
Water Foxtail	*Alopecurus geniculatus*	Sawbeak Sedge	*Carex stipata*
Shortawn Foxtail	*Alopecurus aequalis*	Spike Rush	*Eleocharis palustris*
Bentgrass	*Agrosits* spp.	Slender Rush	*Juncus tenuis*
Spike Bentgrass	*A. exarata*	Grass-leaf rush	*Juncus marginatus*
Redtop	*A. alba* or *gigantea*		
Colonial Bentgrass	*A. tenuis* or *capillaris*		
Mannagrass	*Glyceria* spp.		
Western	*G. occidentalis*		
Northern	*G. borealis*		
Slender-Spiked	*G. leptostachya*		
Rough-Stalked Bluegrass	*Poa trivialis*		
Velvet Grass	*Holcus mollis*		

TABLE 8. GROUNDCOVERS AND GRASSES SUITABLE FOR THE UPPER SIDE SLOPES OF A BIOFILTRATION SWALE	
Groundcovers	
Kinnikinnick*	*Arctostaphylos uva-ursi*
Epimedium	*Epimedium grandiflorum*
—	*Euonymus lanceolata*
Strawberry*	*Fragaria chiloensis*
—	*Genista*
St. John's-Wort	*Hypericum sempervirens*
Broadleaf Lupine*	*Lupinus latifolius*
White Sweet Clover*	*Melilotus alba*
Creeping Forget-Me-Not	*Omphalodes verna*
—	*Rubus calycinoides*
White Lawn Clover	*Trifolium repens*
Yellow-Root	*Xanthorhiza simplissima*
Grasses (drought-tolerant, minimum mowing)	
Buffalo Grass	*Buchloe dactyloides*
Tufted Fescue	*Festuca amethystina*
Tall Fescue *	*Festuca arundinacea*
Hard Fescue	*Festuca ovina duriuscula* (e.g., Reliant, Aurora)
Red Fescue*	*Festuca rubra*
Dwarf Tall Fescues	*Festuca* spp. (e.g., Many Mustang, Silverado)
Blue Oatgrass	*Helictotrichon sempervirens*
Low-growing turf mix: 40% dwarf tall fescue 30% dwarf perennial rye "Barclay" 25% red fescue 5% colonial bentgrass	
* *Native species.* *Notes*: • *Many other ornamental grasses which require only annual mowing are suitable.* • *Ivy is not permitted because of its tendency to spread.*	

Recommended Design Features

The following features should be incorporated into biofiltration swale designs where site conditions allow.

Swale Layout and Grading

1. If the longitudinal slope is less than 1.5% (requiring the use of underdrains along the swale length), the **subgrade** should contain 10% or more of sand to promote

infiltration of standing water. If sand is added to promote drainage, the soil or sand substrate must still be amended with compost.

2. **Underdrains** are also recommended for swales greater than 1.5% longitudinal slope on till soils, especially if it is likely that the swale will intercept groundwater.
3. Biofiltration swales should be aligned to avoid sharp bends where erosion of the swale side slope can occur. However, gradual meandering bends in the swale are desirable for aesthetic purposes and to promote slower flow.

Location and Landscaping

1. During seeding, slow-release **fertilizers** may be applied to speed the growth of grass. Low phosphorus fertilizers (such as formulations in the proportion 3:1:3 N-P-K or less) or a slow-release phosphorus formulation such as rock phosphate or bone meal should be used. A typical fertilizer application rate should be 2 pounds per 1,000 square feet. If animal manure are used in the fertilizer, they must be sterilized to avoid leaching fecal coliform bacteria into receiving waters.
2. Consultation with a **landscape or erosion control specialist** is recommended for project-specific recommendations on grass seed, fertilizer, and mulching applications to ensure healthy grass growth. The **grass mix** should be capable of surviving and remaining healthy under both dry and wet conditions with limited maintenance.
3. A grassy swale should be incorporated into the site landscape design. **Shrubs** may be planted along the edges of a swale (above the water quality treatment level) provided that exposure of the swale bottom to sunlight and maintenance accessibility are not compromised. *Note: For swales used to convey high flows, the plant material selected must bind the soil adequately to prevent erosion.*
4. Swales should not be located in areas where **trees** will drop leaves or needles that can smother the grass or clog part of the swale flow path. Likewise, landscaping plans should take into consideration the problems that **falling leaves and needles** can cause for swale performance and maintenance. Landscape **planter beds** should be designed and located so that soil does not erode from the beds and enter a nearby biofiltration swale.

Construction Considerations

1. If a biofiltration swale is put into operation before all construction in the drainage area of the swale is complete, the swale must be cleaned of sediment and reseeded.
2. It is preferable to provide good erosion control before runoff enters a biofiltration swale. Swales are designed to handle only modest sediment loads from stabilized sites.

Maintenance Considerations

The design criteria given previously have incorporated maintenance concerns into swale design. However, the designer should know the type and frequency of maintenance anticipated so that alternative proposals can incorporate maintenance activity.

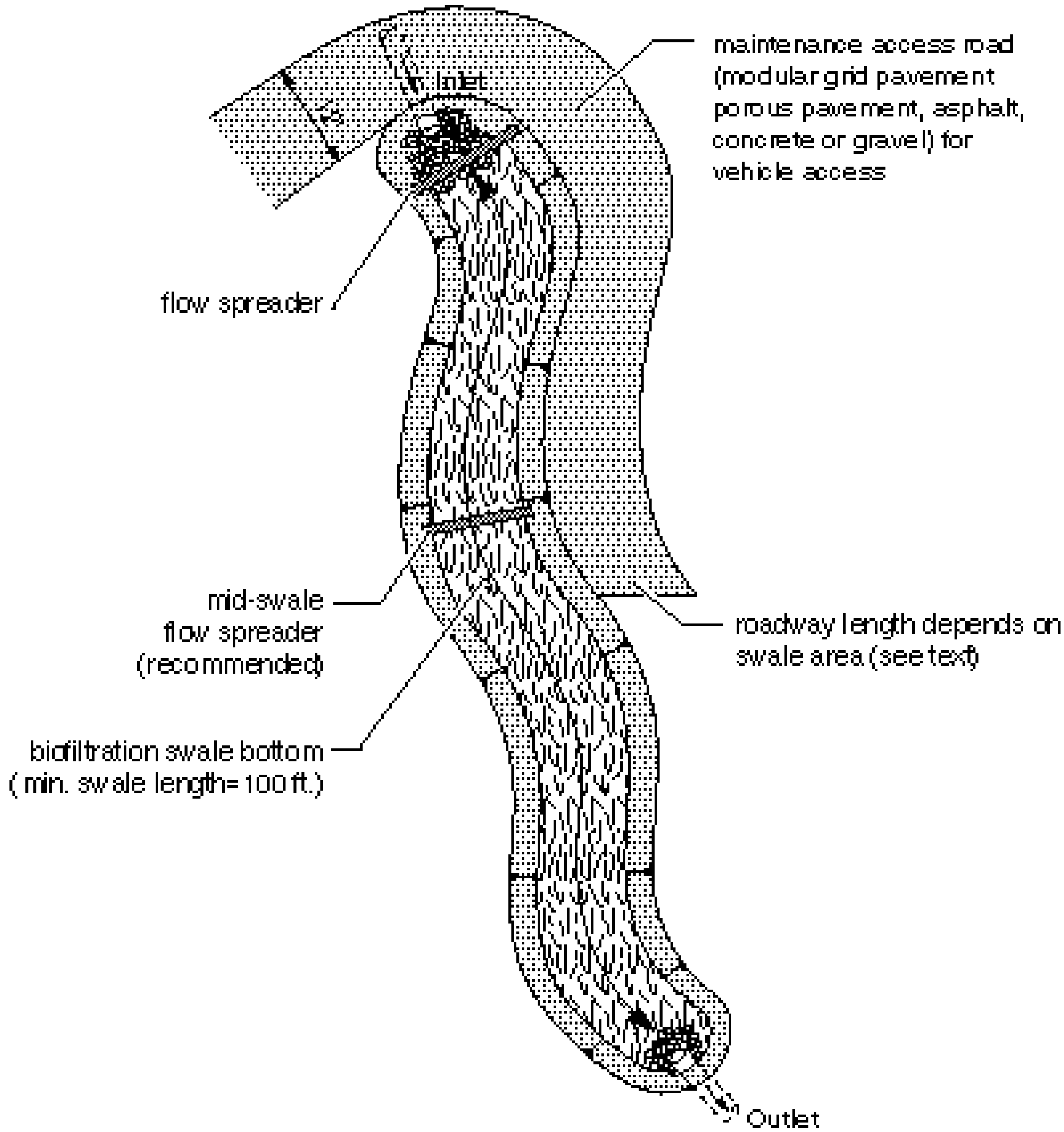
Typical swale maintenance includes routine mowing, sediment and debris removal, and repair of eroded or scoured channel sections as described below.

1. Grass should be **mowed to maintain an average grass height** between 4 inches and 9 inches, depending on the site situation. Monthly mowing is needed from May through September to maintain grass vigor. If a swale is not mowed at least annually, trees and

brush will invade the swale and inhibit grass growth, compromising the swale's performance for water quality treatment.

2. **Grass clippings** and all debris should be removed from the swale and disposed of properly off site.
3. **Sediment** deposited at the head of the swale should be removed if grass growth is being inhibited for more than 10% of the swale length or if the sediment is blocking the even spreading or entry of water to the rest of the swale. Annual sediment removal and spot reseeding will probably be necessary.
4. If flow **channelization or erosion** has occurred, the swale should be regraded to produce a flat bottom width, then reseeded as necessary. If the channel results from constant base flow, it may be better to install a low-flow drain rather than to regrade. Regrading should not be required every year.
5. For swales with underdrains, **vehicular access to the swale bottom** (other than grass mowing equipment) should be avoided because the drainpipe cannot support vehicle weight. Consideration should be given to providing wheel strips in the swale bottom if access is needed.

FIGURE 8. BIOFILTRATION SWALE SCHEMATIC



NOTE: Longitudinal slope 1-6%.
Provide underdrain for slopes < 1.5%.

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FIGURE 9. BIOFILTRATION SWALE CROSS-SECTIONS

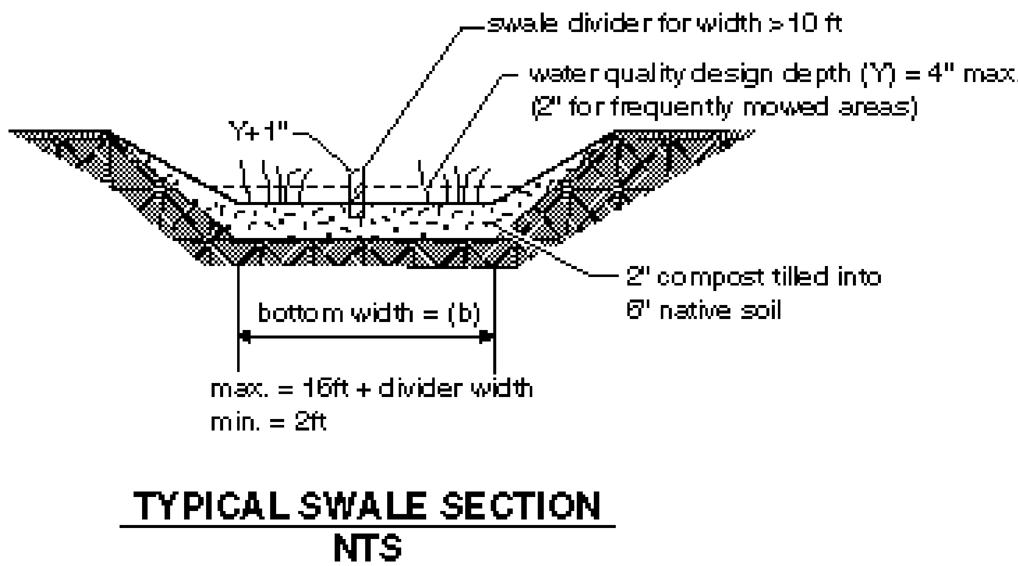
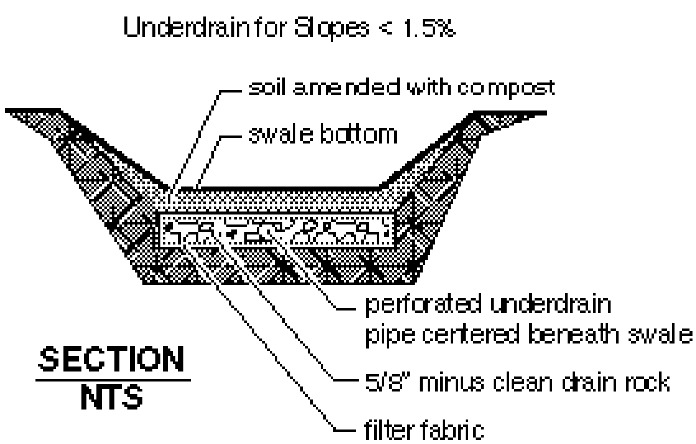
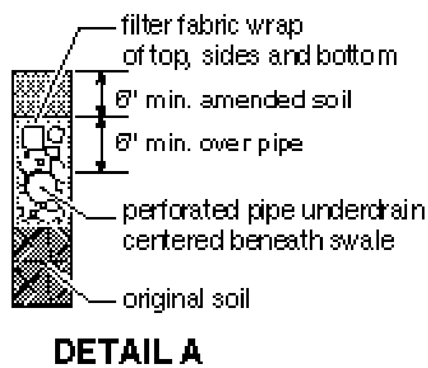


FIGURE 10. BIOFILTRATION SWALE UNDERDRAIN DETAIL





NOTE: Underdrain must infiltrate or drain freely to an acceptable discharge point.

FIGURE 11. BIOFILTRATION SWALE LOW-FLOW DRAIN

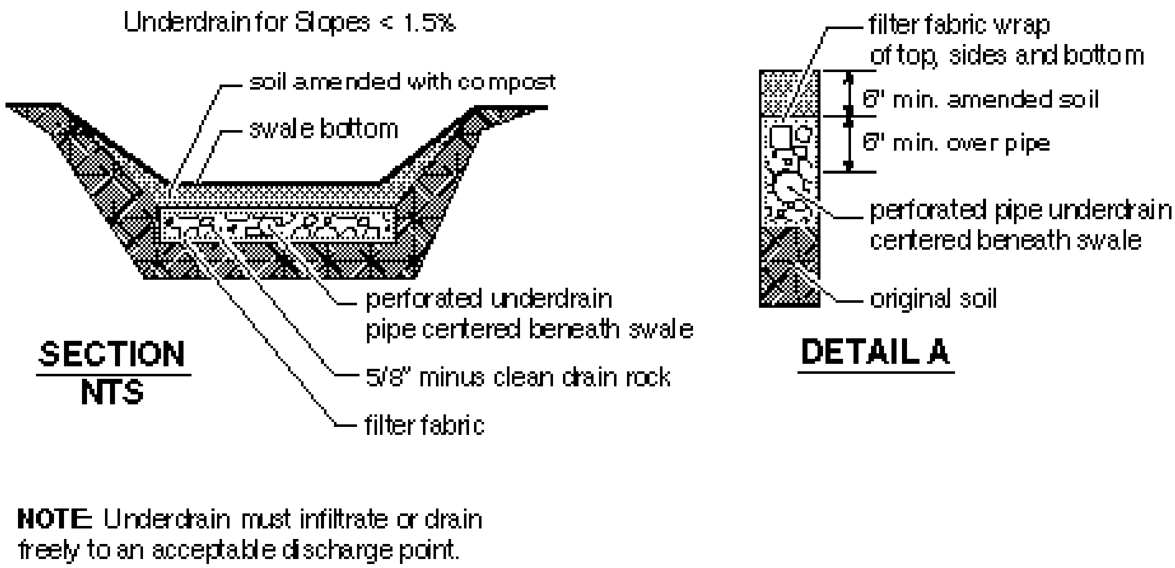
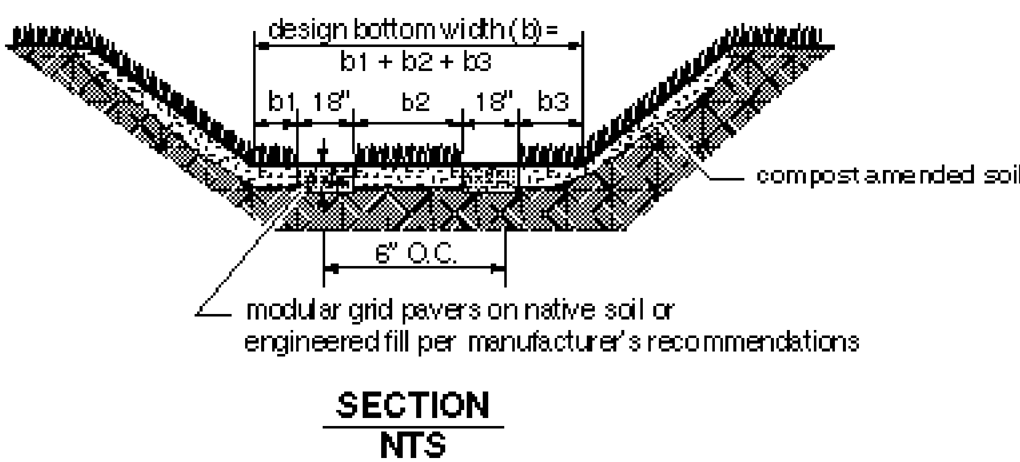


FIGURE 12. BIOFILTRATION SWALE WHEEL STRIPS



3.2 WET BIOFILTRATION SWALES

A *wet biofiltration swale* is a variation of a basic biofiltration swale for use where the longitudinal slope is slight, water tables are high, or continuous low base flow is likely to result in saturated soil conditions. Where saturation exceeds about 2 weeks, typical grasses will die. Thus, vegetation specifically adapted to saturated soil conditions is needed. Different vegetation in turn requires modification of several of the design parameters for the basic biofiltration swale detailed in Section 3.1 (p. 35).

Applications

Wet biofiltration swales are applied where a basic biofiltration swale is desired but not allowed or advisable because one or more of the following conditions exist:

- The swale is on till soils and is downstream of a detention facility providing flow control.
- Saturated soil conditions are likely because of seeps or base flows on the site.
- Longitudinal slopes are slight (generally less than 2%).

3.2.1 Methods of Analysis

Wet biofiltration swales use the **same methods of analysis as basic biofiltration swales** (see p.36) except the following **step is added**:

Step 6: Adjust for extended wet season flow. If the swale will be downstream of a detention facility providing flow control, multiply the treatment area (bottom width times length) of the swale by 2, and readjust the swale length, if desired. Maintain a 5:1 length to width ratio (see criteria under "Swale Geometry" below).

Intent: An increase in the treatment area of swales following detention facility is required because of the differences in vegetation established in a constant flow environment. Although flows following detention are small, and swales are likewise much smaller than those sized for upstream flows, they are much more protracted. These protracted flows result in more stream-like conditions than are typical for other wet biofilter situations. Since vegetation growing in streams is often less dense, this increase in treatment area is needed to ensure that equivalent pollutant removal is achieved in extended flow situations.

3.2.2 Design Criteria

Swale Geometry

Same as specified for **basic biofiltration swales** (see page 52) except for the following **modifications:**

1. **Criterion 1:** The **maximum bottom width** may be increased to 25 feet, but a length-to-width ratio of 5:1 must be provided. No longitudinal dividing berm is needed. *Note: The minimum swale length is still 100 feet.*
2. **Criterion 2:** If **longitudinal slopes** are greater than 2 %, the wet swale must be stepped so that the slope within the stepped sections averages 2%. Steps may be made of retaining walls, log check dams, or short riprap sections. **No underdrain or low-flow drain is required**.

High-Flow Bypass

A high-flow bypass is required for flows greater than the water quality design flow to protect wetland vegetation from damage.[13] The bypass may be an open channel parallel to the wet biofiltration swale.

Water Depth and Base Flow

Same as for basic biofiltration swales (see page 40) except the **design water depth** shall be 4 inches for all wetland vegetation selections, and **no underdrains or low-flow drains are required**.

Flow Velocity, Energy Dissipation, and Flow Spreading

Same as for basic biofiltration swales (see page 40) except **no flow spreader is required**.

Access

Same as for basic biofiltration swales (see page 42) except access is only required to the inflow and the outflow of the swale; access along the length of the swale is not required. Also, wheel strips may not be used for access in the swale.

Intent: An access road is not required along the length of a wet swale because of infrequent access needs. Frequent mowing or harvesting is not desirable. In addition, wetland plants are fairly resilient to sediment-induced changes in water depth, so the need for access should be infrequent.

Soil Amendment

Same as for basic biofiltration swales (see page 43).

Planting Requirements

Same as for **basic biofiltration swales** (see page 43) except for the following **modifications:**

1. A list of acceptable plants with recommended spacing is given in Table 9 (p. 54). In general, it is best to plant several species to increase the likelihood that at least some of the selected species will find growing conditions favorable.
2. A wetland seed mix may be applied by hydroseeding, but if coverage is poor, planting of rootstock or nursery stock is required. Poor coverage is considered to be more than 30% bare area through the upper 2/3 of the swale after four weeks.

Recommended Design Features

Same as for basic biofiltration swales (see page 46).

Construction Considerations

Same as for basic biofiltration swales (see page 47).

Maintenance Considerations

Same as for basic biofiltration swales (see page 47) except mowing of wetland vegetation is not required. However, harvesting of very dense vegetation may be desirable in the fall after plant die-back to prevent the sloughing of excess organic material into receiving waters. Many native

[13] Unlike grass, wetland vegetation will not quickly regain an upright attitude after being laid down by high flows. New growth, usually from the base of the plant, often taking several weeks, is required to regain its upright form.

Juncus species remain green throughout the winter; therefore, fall harvesting of *Juncus* species is not recommended.

TABLE 9. RECOMMENDED PLANTS FOR WET BIOFILTRATION SWALE		
Common Name	**Scientific Name**	**Spacing (on center)**
Shortawn foxtail	*Alopecurus aequalis*	seed
Water foxtail	*Alopecurus geniculatus*	seed
Spike rush	*Eleocharis spp.*	4 inches
Slough sedge*	*Carex obnupta*	6 inches or seed
Sawbeak sedge	*Carex stipata*	6 inches
Sedge	*Carex* spp.	6 inches
Western mannagrass	*Glyceria occidentalis*	seed
Velvetgrass	*Holcus mollis*	seed
Slender rush	*Juncus tenuis*	6 inches
Watercress*	*Rorippa nasturtium-aquaticum*	12 inches
Water parsley*	*Oenanthe sarmentosa*	6 inches
Hardstem bulrush	*Scirpus acutus*	6 inches
Small-fruited bulrush	*Scirpus microcarpus*	12 inches

** Good choices for swales with significant periods of flow, such as those downstream of a detention facility.*

Note: Cattail (Typha latifolia) is not appropriate for most wet swales because of its very dense and clumping growth habit which prevents water from filtering through the clump.

3.3 CONTINUOUS INFLOW BIOFILTRATION SWALES

In situations where water enters a biofiltration swale continuously along the side slope rather than discretely at the head, a different design approach–the continuous inflow biofiltration swale–is needed. The basic swale design (see Section 3.1, p. 35) is modified by increasing swale length to achieve an equivalent average residence time.

Applications

A continuous inflow biofiltration swale is to be **used when inflows are not concentrated**, such as locations along the shoulder of a road without curbs. This design may also be **used where frequent, small point flows enter a swale**, such as through curb inlet ports spaced at intervals along a road, or from a parking lot with frequent curb cuts. In general, no inlet port should carry more than about 10% of the flow. A continuous inflow swale is not appropriate for a situation in which significant lateral flows enter a swale at some point downstream from the head of the swale. In this situation, the swale width and length must be recalculated from the point of confluence to the discharge point in order to provide adequate treatment for the increased flows.

3.3.1 Methods of Analysis

The design flow for continuous inflow swales must include runoff from the pervious side slopes draining to the swale along the entire swale length. The method of analysis for continuous inflow swales is the same as for basic biofiltration swales (see Section 3.1.1, p. 36) except for the following **clarification of Step 1** and **modification to Step 4**:

- **Step 1:** The water quality design flow can be variable to reflect the increase in flows along the swale length. If only a single design flow is used, the flow at the outlet should be used.
- **Step 4:** Double the hydraulic residence time so that it is a minimum of 18 minutes (1,080 seconds). Equation (3-5) becomes:

$$L = 1080 V_{wq} \tag{3-8}$$

where L = minimum allowable swale length (ft)
V_{wq} = design flow velocity calculated in Step 3 (fps).

Note: Although bottom widths can be increased to reduce length, bottom width cannot be reduced because Manning's depth-velocity-flow rate relationships would not be preserved.

3.3.2 Design Criteria

Same as specified for **basic biofiltration swales** (in Section 3.1.2, p. 39) except for the following **modification:**

Planting Requirements, Criterion 4: For continuous inflow biofiltration swales, interior side slopes above the water quality design treatment elevation shall be planted in grass. A typical lawn seed mix or the biofiltration seed mixes are acceptable. Landscape plants or groundcovers other than grass may not be used anywhere between the runoff inflow elevation and the bottom of the swale.

Intent: The use of grass on interior side slopes reduces the chance of soil erosion and transfer of pollutants from landscape areas to the biofiltration treatment area.

3.4 BASIC FILTER STRIPS

A *filter strip* is a grassy slope located adjacent and parallel to a impervious area such as a parking lot, driveway, or roadway (see the filter strip detail in Figure 14 on page 64). A filter strip is graded to maintain sheet flow of stormwater runoff over the entire width of the strip. A filter strip removes pollutants primarily by means of filtration by grass blades which enhance sedimentation, and the trapping and adhesion of pollutants to the grass and thatch. Pollutants can also be adsorbed by the underlying soil when infiltration occurs, but the extent of infiltration depends on the type of soil, the density of the grass, and the slope of the strip.

In this manual, design procedures are provided for two types of filter strip applications: (1) the basic filter strip that should typically apply to parking lots, driveways, and roads where sufficient space is available, and (2) a modified, narrow area filter strip for roadside applications with limited right-of-way space that constricts the filter strip sizing. The basic filter strip is covered in this section, and the narrow area filter strip is covered in Section 3.5.

Applications and Limitations

Filter strip design is based on the expectation that water will flow fairly evenly across the entire width and length of the strip area. Thus, paved sites without underground stormwater collection systems, gutters, or other runoff control features are good candidates for filter strips.

Filter strips are suitable for sites that meet the following conditions:

- Stormwater runoff from the area requiring treatment should be uniformly distributed along the top of the entire filter strip. If stormwater runoff from the entire site cannot be spread evenly along the top of the filter strip, the filter strip should be applied only to flows that can be uniformly distributed. A different stormwater treatment facility, such as a swale, should be used for areas of the site with concentrated flow (for instance, at road intersections).
- The flow path draining to the filter strip should not exceed 150 feet. Runoff flows traveling greater distances tend to concentrate before entering the filter strip.
- The lateral slope of the drainage area contributing flows to the filter strip (parallel to the edge of pavement) should be less than 2%. A stepped series of flow spreaders installed at the head of the strip could compensate for slightly steeper slopes (see "Flow Spreading and Energy Dissipation," p. 60).
- The longitudinal slope of the contributing drainage area (parallel to the direction of flow entering the filter strip) should be less than 5%. Contributing drainage areas with slopes steeper than 5% should either use a different water quality facility or must provide energy dissipation and flow spreading mechanisms upslope of the upper edge of the filter strip.

A filter strip generally requires more land area than a biofiltration swale because the flow depth through the filter is shallower than through a swale. Although the space requirements may be greater, the filter strip is a viable water quality treatment option in locations where grassy slopes already exist, or where a slope can be incorporated easily into the landscape design for the site. Other limitations that should be considered are listed below:

1. Filter strips are susceptible to short-circuiting via flow channelization because they rely on a large smoothly graded area. If rills, gullies, or channels occur in the filter strip area, inflows will travel too quickly through the filter strip, reducing contact time and pollutant removal performance. A filter strip slope with uneven grading perpendicular to the sheet

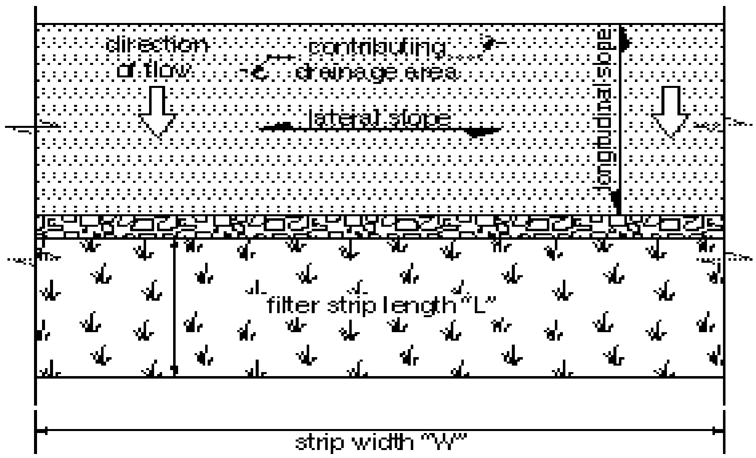
flow path will develop flow channels over time. These problems can be overcome with careful site planning, good soil compaction, skillful grading, and periodic maintenance.

2. Filter strip areas cannot be used for material storage or any activities that could cause disturbance of the ground surface in a manner that could create or promote preferential flow paths (rills or channels) in the filter strip.
3. Filter strips should not be located in shaded areas, for filter strips require exposure to sunlight to ensure healthy grass growth.

3.4.1 Methods of Analysis

In this manual, *filter strip length* is defined as the length of the flow path through the strip. Strip width is typically the same as the extent of pavement along the upstream edge of the strip. Thus, in sizing filter strips, the length is normally the dimension to be sized (see Figure 13 below for definitions of terms).

FIGURE 13. FILTER STRIP TERMINOLOGY



The procedure for filter strip design (described below) relies on Manning's equation to calculate some design variables. It is recognized that there are problems in this application.[14] The filter strip sizing method will be modified as new research results become available.

Step 1: Calculate design flow. Determine the water quality design flow Q_{wq} (see Section 2.1, p. 11).

Step 2: Calculate design flow depth. The design flow depth is calculated based on the width of the filter strip (typically equivalent to the length of the edge of impervious surface contributing flow to the filter strip) and the longitudinal slope of the filter strip (parallel to the direction of flow) using a form of Manning's equation as follows:

$$Q_{wq} = \frac{1.49}{n_{wq}} W d_f^{1.67} s^{0.5} \qquad (3\text{-}9)$$

where Q_{wq} = water quality design flow (cfs)

[14] Ree, W.O., F.L. Wimberley, and F.R. Crow. 1977. Manning *n* and the overland flow equation. Transactions of the American Society of Agricultural Engineers 20 (89).

n_{wq} = Manning's roughness coefficient (either 0.35 or 0.45; see the criteria under "Filter Strip Geometry and Flow Resistance," p. 60)
W = width of filter strip perpendicular to the direction of flow (ft) (≅ length of impervious surface contributing flow)
d_f = design depth of flow (ft), which is also assumed to be the hydraulic radius (maximum 1 inch, or 0.083 feet; see the criteria under "Water Depth and Velocity," p. 60)
s = longitudinal slope of filter strip parallel to the direction of flow (ft/ft) (averaged over the width of the filter strip; all portions averaged must also meet the slope design criteria).

Rearranging the above equation, the design depth of flow can be calculated using the following equation:

$$d_f = \left(\frac{Q_{wq}\, n_{wq}}{1.49Ws^{0.5}}\right)^{0.6} \qquad (3\text{-}10)$$

If the calculated flow depth exceeds 1 inch (0.083 feet), the design flow rate routed through the strip must be reduced. If this is not feasible, it is not possible to use a filter strip.

Step 3: Calculate design flow velocity through filter strip. The design flow velocity V_{wq} is based on the water quality design flow rate, the width of the filter strip, and the calculated design flow depth from Step 2 using the following equation:

$$V_{wq} = \frac{Q_{wq}}{Wd_f} \qquad (3\text{-}11)$$

where V_{wq} = design flow velocity (fps)
W = strip width (ft) (parallel to the edge of pavement)
d_f = water depth (ft).

If V_{wq} exceeds 0.5 feet per second, a filter strip may not be used. Either redesign the site to provide a gentler longitudinal slope for the strip, or select a different water quality facility.

Step 4: Calculate required length of filter strip. Determine the required length L of the filter strip to achieve a desired hydraulic residence time of at least 9 minutes (540 seconds) using the following equation:

$$L = 540V_{wq} \qquad (3\text{-}12)$$

where L = filter strip length (ft)
V_{wq} = design flow velocity from Step 3 (fps)

3.4.2 Design Criteria

Figure 14 (p. 64) shows typical filter strip details. The most effective filter strips achieve uniform sheet flow under all runoff flow conditions. To achieve proper flow conditions, the following basic design requirements apply.

Drainage Area Restrictions

1. The **longest flow path** from the area contributing sheet flow to the filter strip shall not exceed 150 feet.
2. The **lateral slope of the contributing drainage** (parallel to the edge of pavement) shall be 2% or less.
3. A stepped series of **flow spreaders** installed at the head of the strip may be used to compensate for drainage areas having lateral slopes of up to 4% (see Section 2.5, p. 27, for information on flow spreader designs).
4. The **longitudinal slope of the contributing drainage area** (parallel to the direction of flow entering the filter strip) should be 5% or less.
5. Contributing drainage areas with longitudinal slopes steeper than 5% should either use a different water quality facility or provide energy dissipation and flow spreading options upslope of the upper edge of the filter strip to achieve flow characteristics equivalent to those meeting the Criteria in items 2 and 4 above.

Filter Strip Geometry and Flow Resistance

1. The **longitudinal slope** of a filter strip (along the direction of flow) shall be between 1% minimum and 15% maximum.
2. The **lateral slope** of a strip (parallel to the edge of pavement, perpendicular to the direction of flow) shall be less than 2%.
3. The **ground surface** at the upper edge of a filter strip (adjacent to the contributing drainage area) shall be at least 1 inch lower than the edge of the impervious area contributing flows.
4. Manning's **roughness coefficient (n_{wq})** for flow depth calculations shall be 0.35. An exception to this requirement may be made for situations where the filter strip will be mowed weekly in the growing season to consistently provide a grass height of less than 4 inches; in this case, the value of n_{wq} in Equation (3-10) may be set to 0.45. *Note: In filter strip design, a larger* n *value results in a smaller strip size.*

Water Depth and Velocity

1. The **maximum depth** of flow through a filter strip for the water quality design flow shall be 1.0 inch.
2. The **maximum allowable flow velocity** for the water quality design flow V_{wq} shall be 0.5 feet per second.

Flow Spreading and Energy Dissipation

1. Runoff entering a filter strip must not be concentrated. A **flow spreader** shall be installed at the edge of the pavement to uniformly distribute the flow along the entire width of the filter strip.

2. At a minimum, a **gravel flow spreader** (gravel-filled trench) shall be placed between the impervious area contributing flows and the filter strip, and meet the following requirements:
    a) The gravel flow spreader shall be a minimum of 6 inches deep and shall be 18 inches wide for every 50 feet of contributing flow path.
    b) The gravel shall be a minimum of 1 inch below the pavement surface.

       Intent: This allows sediment from the paved surface to be accommodated without blocking drainage onto the strip.
    c) For strips less than 50 feet, the spreader width may be reduced to a minimum of 12 inches.
    d) Where the ground surface is not level, the gravel spreader must be installed so that the bottom of the gravel trench and the outlet lip are level.
    e) Along **roadways**, gravel flow spreaders must meet the specification for shoulder ballast given in Section 9-03.9(2). of the current WSDOT/APWA *Standard Specifications for Road, Bridge and Municipal Construction.* The ballast shall be compacted to 90 percent standard proctor.

       Intent: This specification was chosen to meet traffic safety concerns as well as to limit fines to less than 2% passing the No. 100 sieve.
3. Other flow spreaders (see Section 2.5, p. 27) may also be used. For filter strip applications, the notched curb spreader and through-curb port spreaders may not be used without also adding a gravel spreader to better ensure that water sheet-flows onto the strip.
4. **Energy dissipaters** are needed in a filter strip if sudden slope drops occur, such as locations where flows in a filter strip pass over a rockery or retaining wall aligned perpendicular to the direction of flow. Adequate energy dissipation at the base of a drop section can be provided by a riprap pad (see Table 4 on page 29 for guidance).

Access

Access shall be provided at the **upper edge of a filter strip** to enable maintenance of the inflow spreader throughout the strip width and allow access for mowing equipment.

Soil Amendment

1. Two inches (minimum) of **well-rotted compost** shall be provided for the entire filter strip treatment area to amend the topsoil unless the soil already has an organic content of 5%[15] or greater. The compost must be tilled into the underlying native soil to a depth of 6 inches to prevent washing out the compost and avoid creating a defined layer of different soil types that can prevent downward percolation of water.
    a) Compost shall meet City of Seattle specifications for **decomposed organic mulch** (City of Seattle *Standard Specifications for Road, Bridge and Municipal Construction,* 2000 Edition) and not contain any sawdust, straw, green or under-composted organic matter, or toxic or otherwise harmful materials.
    b) Compost should not contain unsterilized manure because it can leach fecal coliform bacteria into receiving waters.

[15] Note: The King County *Surface Water Design Manual* (1998) allows a different minimum organic content.

2. **Soil or sod** with a clay content of greater than 10% should be avoided. If there is potential for contamination of the underlying groundwater, the filter strip should be lined with a treatment liner to prevent groundwater contamination. See Section 2.4 (p. 17) for details on soil liner options.

Planting Requirements

1. **Grass** shall be established throughout the entire treatment area of the filter strip.
2. **Sod** may be used instead of grass seed as long as the entire filter strip area is completely covered with no gaps between sod pieces.
3. Filter strips are subject to drier conditions than biofiltration swales and also may be more vulnerable to erosion than swales. For these reasons, the following permanent **erosion-control grass seed mix** shall be applied at a rate of 80 pounds per acre in filter strips (percentages are by weight):

   40% turf-type rye

   40% fescue

   10% white dutch clover

   10% colonial bentgrass
4. **Alternate seed mixes** may be used if a horticultural or erosion-control specialist recommends a different mix and if erosion prevention is adequately addressed by other erosion-control measures.
5. Seed may be applied by **hydroseeding or broadcast application**.
6. **Seeding** is best performed in spring (mid-March to June) or fall (late September to October). If seed is applied in the spring or summer, irrigation must be provided to ensure grass survival.
7. Runoff shall be diverted around a filter strip until the grass is established.

Recommended Design Features

Where conditions allow, the following features should be incorporated into a filter strip's design and its corresponding site configuration.

Site Layout and Landscaping

1. Filter strips should be incorporated into the **landscape design** for a site; however, the treatment areas (i.e., grassy areas) should not be fertilized unless needed for healthy grass growth.
2. **Curbs** should be avoided, if possible, at the downslope edge of the contributing area. If curbing is needed, through-curb ports shall be provided (see Section 2.5, p. 27).
3. If **parking lot wheel stops** are necessary, individual wheel stops should have gaps for water to pass through. The shorter the wheel stops, the better for sheet flow purposes. See Section 2.5 (p. 27) for requirements.
4. During seeding, slow-release **fertilizers** may be applied to speed the growth of grass. Low phosphorus fertilizers (such as formulations in the proportion 3:1:3 N-P-K or less) or a slow-release phosphorus formulation such as rock phosphate or bone meal should be used.

5. Filter strips should be well defined on a site and **marked with signs** to prevent future destruction or alteration of the treatment areas. Small at-grade signage is preferred.

Maintenance Features

1. **Irrigation** may be required in the summer months following initial filter strip construction to prevent the filter strip grass from wilting or dying. Site planning should address the need for sprinklers or other means of irrigation.
2. **Flatter slopes** are preferred for filter strips to make grass mowing easier.

Use with High-Use Site Facility

A high-use site (see Section 1.1, p. 2) may employ a filter strip to meet the *basic stormwater treatment requirement* if a **linear sand filter** (see Section 5.4, p. 137) is used to meet the *high-use site treatment facility* requirement. In this situation, the sand filter should be designed so that flows exit the underdrain gravel along the whole length of the trench directly to the filter strip.

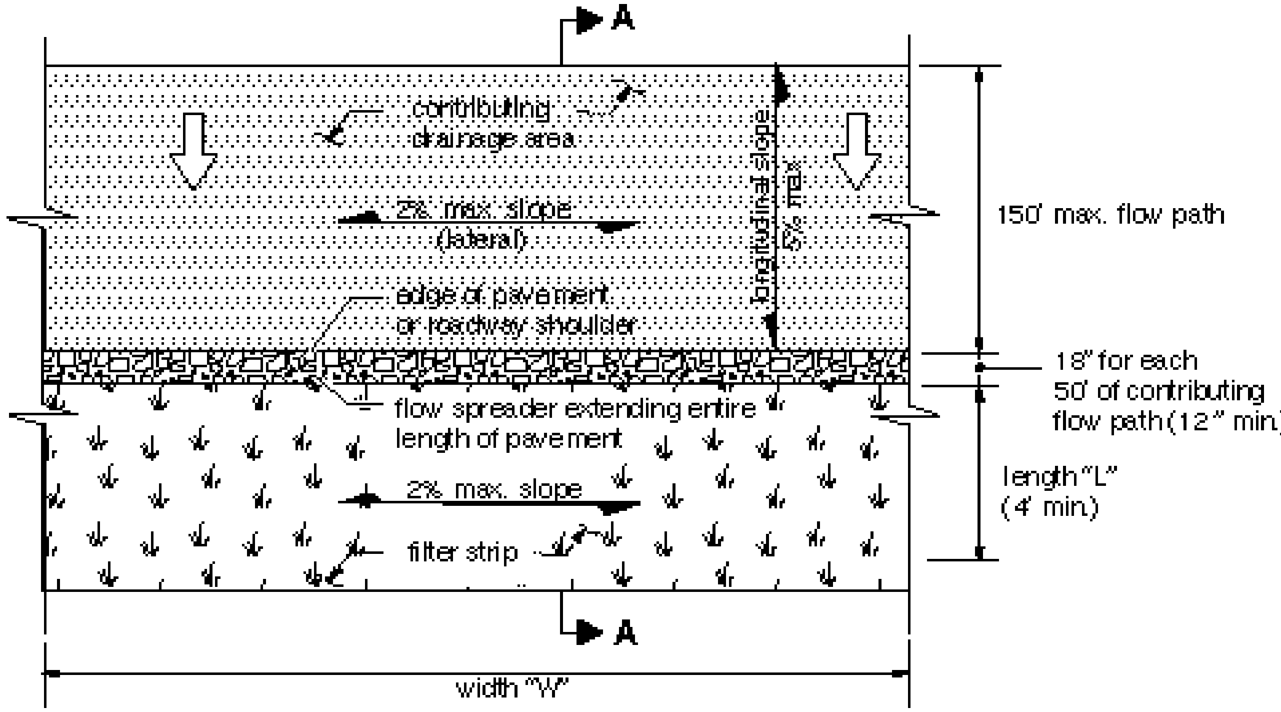
Construction Considerations

1. If a filter strip is put into operation before all construction in the contributing drainage catchment has been completed, the strip must be cleaned of sediment and reseeded.
2. It is preferable to provide erosion control before construction-phase sediment enters the filter strip. Filter strips are designed to handle only modest sediment loads without frequent maintenance.

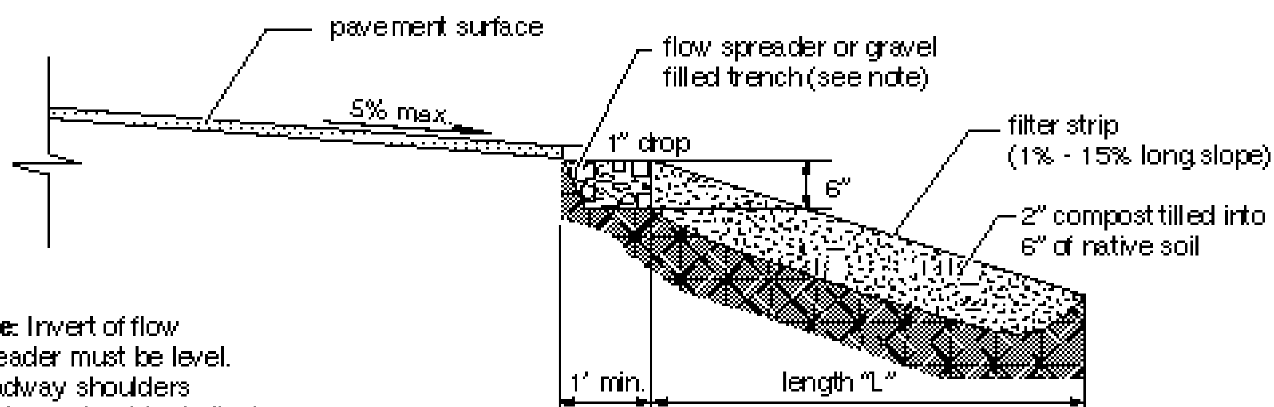
Maintenance Considerations

Maintenance considerations, including mowing frequency and sediment removal, are similar to those for biofiltration swales (see page 47).

FIGURE 14. TYPICAL FILTER STRIP DETAILS



PLAN VIEW
NTS



Note: Invert of flow spreader must be level. Roadway shoulders must use shoulder ballast.

SECTION A-A
NTS

3.5 NARROW AREA FILTER STRIPS

This section describes a filter strip design[16] for impervious areas with flow paths of 30 feet or less that can drain along their widest dimension to grassy areas (see Figure 13, p. 58, for definitions of filter strip geometry terms).

The treatment objectives, applications and limitations, design criteria, materials specifications, and construction and maintenance requirements set forth in the basic filter strip design apply to narrow filter strip applications.

If space is available to use the basic filter strip design, that design should be used in preference to the narrow filter strip. However, along roadways with limited right-of-way, or for narrow parking strips, the narrow strip may be used.

3.5.1 Methods of Analysis

The sizing of a narrow area filter strip is based on the length of flow path draining to the filter strip and the longitudinal slope of the filter strip itself (parallel to the flow path).

Step 1: Determine length of flow path draining to filter strip. Determine the length of the flow path from the upstream to the downstream edge of the impervious area draining sheet flow to the strip. Normally this is the same as the width of the paved area, but if the site is sloped, the flow path may be longer than the width of the impervious area.

Step 2: Determine average longitudinal slope of filter strip. Calculate the longitudinal slope of the filter strip (along the direction of unconcentrated flow), averaged over the total width of the filter strip. The minimum sizing slope is 2%. The maximum allowable filter strip slope is 20%. If the slope exceeds 20%, the filter strip must be stepped down the slope so that the treatment areas between drop sections do not have a longitudinal slope greater than 20%. Drop sections must be provided with erosion protection at the base and flow spreaders to re-spread flows. Vertical drops along the slope must not exceed 12 inches in height. If this is not possible, a different treatment facility must be selected.

Step 3: Determine required length of filter strip. Select the appropriate filter strip length for the flow path length and filter strip longitudinal slope (Steps 1 and 2 above) **from the graph in** Figure 15 (p. 66).[17] The filter strip must be designed to provide this minimum length *L* along the entire stretch of pavement draining into it.

To use the graph: Find the **length of the flow path** on one of the curves (interpolate between curves as necessary). Move along the curve to the point where the **design longitudinal slope** of the filter strip (x-axis) is directly below. Read the filter **strip length** on the y-axis which corresponds to the intersection point.

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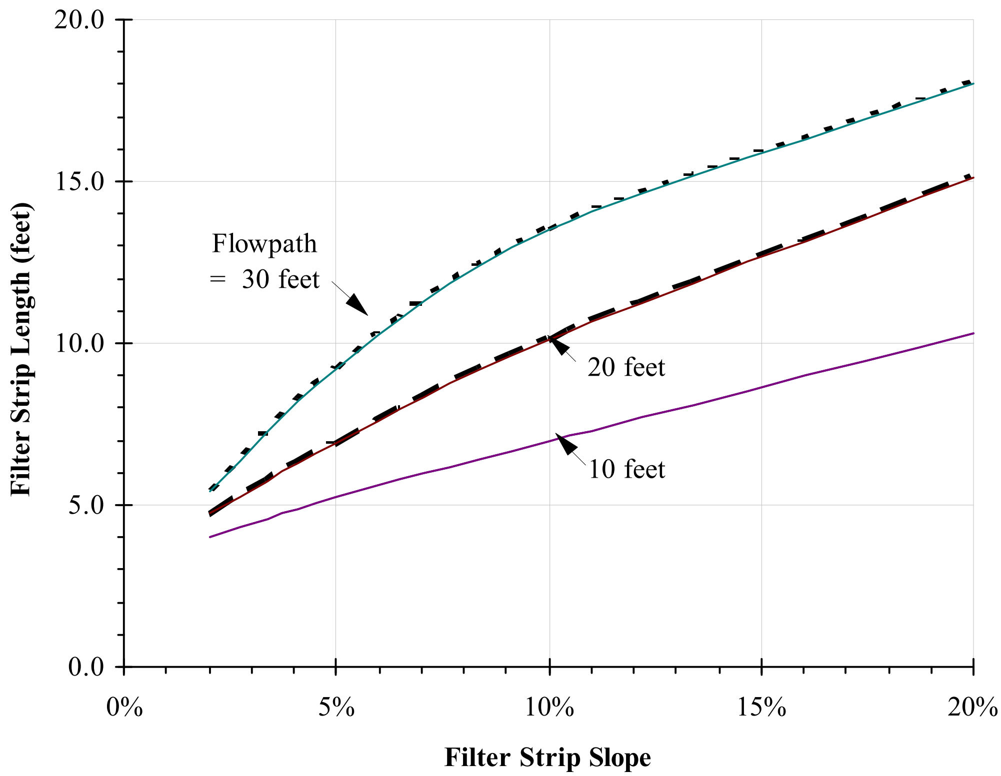
16 This narrow area filter strip design method is included here because technical limitations exist in the basic design method which result in filter strips that are proportionately longer as the contributing drainage becomes narrower (a result that is counter-intuitive). Research by several parties is underway to evaluate filter strip design parameters. This research may lead to more stringent design requirements that would supersede the design criteria presented here.

17 The filter strip length requirements reflected in Figure 15 are scaled from dimensions of biofiltration swale treatment areas for the same slope and flow rate conditions.

Example

If the length of flow path through a parking strip is 20 feet and the filter strip will be at 5% longitudinal slope, move along the middle curve until it intercepts the 5% grid from the x-axis. The required filter strip length is 7 feet (read from the y-axis).

FIGURE 15. FILTER STRIP LENGTHS FOR NARROW RIGHT-OF-WAY



Note: minimum allowable filter strip length is 4 feet

3.5.2 Design Criteria

Required and recommended design criteria for narrow area filter strips are the **same as specified for basic filter strips**. Note that for roadway applications, gravel spreaders must meet the specification for shoulder ballast given in Section 9-03.9(2) of the current *WSDOT/APWA Standard Specifications for Road, Bridge and Municipal Construction* compacted to 90% standard proctor.

4 WETPOOL FACILITY DESIGNS

This section presents the methods, criteria, and details for analysis and design of wetponds, wetvaults, and stormwater wetlands. These facilities have as a common element a permanent pool of water, the *wetpool*. Each of the wetpool facilities can be combined with a detention or flow control facility in a combined facility. Included are the following specific facility designs:

- Wetponds, Section 4.1 (p. 68)
- Wetvaults, Section 4.2 (p.91)
- Stormwater Wetlands, Section 4.3 (p. 98)
- Combined Detention and Wetpool Facilities, Section 4.4 (p. 104)

The information presented for each facility is organized into the following two categories:

1. **Methods of Analysis:** Contains a step-by-step procedure for designing and sizing each facility. Information used in the procedure is based on available literature but clarified or modified where deficiencies were identified.[18]
2. **Design Criteria:** Contains the details, specifications, and material requirements for each facility.

4.1 WETPONDS[19]

A *wetpond* is a constructed stormwater pond that retains a permanent pool of water (a "wetpool") at least during the wet season (see the wetpond detail in Figure 20 (p. 88). The volume of the wetpool is related to the effectiveness of the pond in settling particulate pollutants.

Applications and Limitations

A wetpond requires a larger area than a biofiltration swale or a sand filter, but it can be integrated to the contours of a site fairly easily. In till soils, the wetpond holds a permanent pool of water that provides an attractive aesthetic feature. In more porous soils, wetponds may still be used, but water seepage from unlined cells could result in a dry pond, particularly in the summer months. Lining with impervious material is one way to deal with this situation.

Wetponds may be single-purpose facilities, providing only water quality treatment, or they may be combined with a detention facility to also provide flow control. If combined, the wetpond can often be stacked under the detention facility with little further loss of development area. See Section 4.4 (p. 104) for a description of combined water quality and detention facilities.

Wetponds treat water both by gravity settling and by biological uptake of algae and microorganisms. Wetponds can remove some dissolved pollutants such as soluble phosphorus by this uptake mechanism. Wetponds work best when the water already in the pond is moved out *en masse* by incoming flows, a phenomena called "**plug flow**." Because treatment works on this displacement principle, the dead storage pool of wetponds may be provided below the groundwater level without interfering unduly with treatment effectiveness. However, if

[18] Such modifications were often based on computer modeling using the King County Runoff Time Series (KCRTS) model. Less frequently they were based on bench-scale studies.

[19] Note: The King County *Surface Water Design Manual* (1998) includes specifications for both *basic* and *large* wetponds. The requirements in the Seattle *Stormwater, Grading and Drainage Control Code* can be met by the basic wetpond described here.

combined with a detention function, the live storage must be above the seasonal high groundwater level.

4.1.1 Methods of Analysis

The primary design factor that determines a wetpond's **particulate removal efficiency** is the volume of the wetpool in relation to the volume of stormwater runoff from the *mean annual storm*.[20] The larger the wetpond volume in relation to the volume of runoff, the greater the potential for pollutant removal. Also important are the avoidance of short-circuiting and the promotion of plug flow. *Plug flow* describes the hypothetical condition of stormwater moving through the pond as a unit, displacing the "old" water in the pond with incoming flows. To prevent short-circuiting, water is forced to flow, to the extent practical, to all potentially available flow routes, avoiding "dead zones" and maximizing the time water stays in the pond during the active part of a storm.

Design features that encourage plug flow and avoid dead zones are as follows:

- Dissipating energy at the inlet
- Providing a large length-to-width ratio
- Providing a broad surface for water exchange across cells rather than a constricted area.

Maximizing the flow path between inlet and outlet, including the vertical path, also enhances treatment by increasing residence time. The actual performance of a wetpond may vary, however, due to a number of factors, including design features, maintenance frequency, storm characteristics, pond algae dynamics, and waterfowl use.

Procedures for determining a wetpond's dimensions and volume are outlined below.

Step 1: Identify required wetpool volume factor (*f*). A basic wetpond requires a volume factor of **3**. This means that the required wetpond volume is 3 times the volume of runoff V_r from the mean annual storm (see Steps 2 and 3).

Step 2: Determine rainfall (R) for the mean annual storm. For Seattle, the mean annual storm is 0.47 inches. For other locations, the rainfall for the mean annual storm *R* is obtained by locating the project site on an isopluvial map and interpolating between isopluvials.

Step 3: Calculate runoff from the mean annual storm (V_r) for the developed site. The runoff volume V_r is the amount of rainfall that runs off a particular set of land covers. To determine V_r, each portion of the wetpond tributary area is assigned to one of four cover types, each having a different runoff coefficient: impervious surface, till grass, till forest, or outwash.

- **Impervious surface** is a compacted surface, such as pavement, gravel, soil, or other hard surfaces, as well as open water bodies.

- **Till grass** is post-development grass or landscaped area and onsite forested land on till soil that are not permanently in sensitive area buffers or covenants. *Till* is soil that does not drain readily and, as a result, generates large amounts of runoff. For this application, till soil types include Buckley and bedrock soils, and alluvial and outwash soils that have a seasonally high water table or are underlain at a shallow depth (less than 5 feet) by glacial till. U.S. Soil Conservation Service (SCS) hydrologic soil groups that are

[20] The *mean annual storm* is a statistically derived rainfall event defined by the U.S. Environmental Protection Agency in "Results of the Nationwide Urban Runoff Program," 1986. It is defined as the annual rainfall divided by the number of storm events in the year. The NURP studies refer to pond sizing using a V_b/V_r ratio: the ratio of the pond volume V_b to the volume of runoff from the mean annual storm V_r. This is equivalent to using a volume factor *f* times V_r.

classified as till soils include a few B, most C, and all D soils. See Table 10 for classification of specific SCS soil types.

- **Till forest** is all permanent onsite forest and/or shrub cover located on till soils that retains the natural understory vegetation and forest duff, irrespective of age, if densities are sufficient to ensure at least 80% canopy cover within 5 years. To be counted in this category, forest must be protected as permanent open space. Such areas may be placed in a separate open space tract or may be protected through covenants or conservation easements.
- **Outwash** is soil that infiltrates well and as a result produces small amounts of runoff. SCS hydrologic soil groups classified as outwash soils include all A, most B, and some C soils. See Table 10 for classification of specific SCS soil types. Cover categories are based on existing U.S. Department of Agriculture soil survey data or site specific data where available.

Next, coefficients specific to the four cover types are weighted by the drainage areas and then multiplied by the rainfall R from Step 2 to produce the runoff volume V_r:

$$V_r = (0.9A_i + 0.25A_{tg} + 0.10A_{tf} + 0.01A_o) \text{ x } (R/12) \qquad (4\text{-}1)$$

where
V_r = volume of runoff from mean annual storm (cf)
A_i = area of impervious surface (sf)
A_{tg} = area of till soil covered with grass (sf)
A_{tf} = area of till soil covered with forest (sf)
A_o = area of outwash soil covered with grass or forest (sf)
R = rainfall from mean annual storm (inches)

Step 4: Calculate wetpool volume (V_b). Use the results of the previous steps to calculate the required wetpool volume according to the following equation:

$$V_b = f\,V_r \qquad (4\text{-}2)$$

where
V_b = wetpool volume (cf)
f = volume factor from Step 1
V_r = runoff volume (cf) from Step 3

Step 5: Determine wetpool dimensions. Determine the wetpool dimensions satisfying the design criteria outlined below. A simple way to check the volume of each wetpool cell is to use the following equation:

$$V_b = \frac{h(A_1 + A_2)}{2} \qquad (4\text{-}3)$$

where
V_b = wetpool volume (cf)
h = wetpool depth (ft)
A_1 = water quality design surface area of wetpool (sf)
A_2 = bottom area of wetpool (sf)

Step 6: Design pond outlet pipe and determine primary overflow water surface. The design criteria for wetponds (see Section 4.1.2) calls for a pond outlet pipe to be placed on a reverse grade from the pond's wetpool to the outlet structure. The City of Seattle minimum pipe size is 6 inches, and the minimum recommended orifice size is 0.5 inches. Use the following procedure to design the pond outlet pipe and determine the primary overflow water surface elevation:

a) Use the nomographs (see Figure 16 and Figure 17) to select a trial size for the pond outlet pipe sufficient to pass the water quality design flow Q_{wq}.

b) Use Figure 18 to determine the critical depth d_c at the outflow end of the pipe for Q_{wq}.

c) Use Figure 19 to determine the flow area A_c at critical depth.

d) Calculate the flow velocity at critical depth using continuity equation ($V_c = Q_{wq} / A_c$).

e) Calculate the velocity head V_H ($V_H = V_c^2 / 2g$, where g is the gravitational constant, 32.2 feet per second).

f) Determine the primary overflow water surface elevation by adding the velocity head and critical depth to the invert elevation at the outflow end of the pond outlet pipe (i.e., overflow water surface elevation = outflow invert + d_c + V_H).

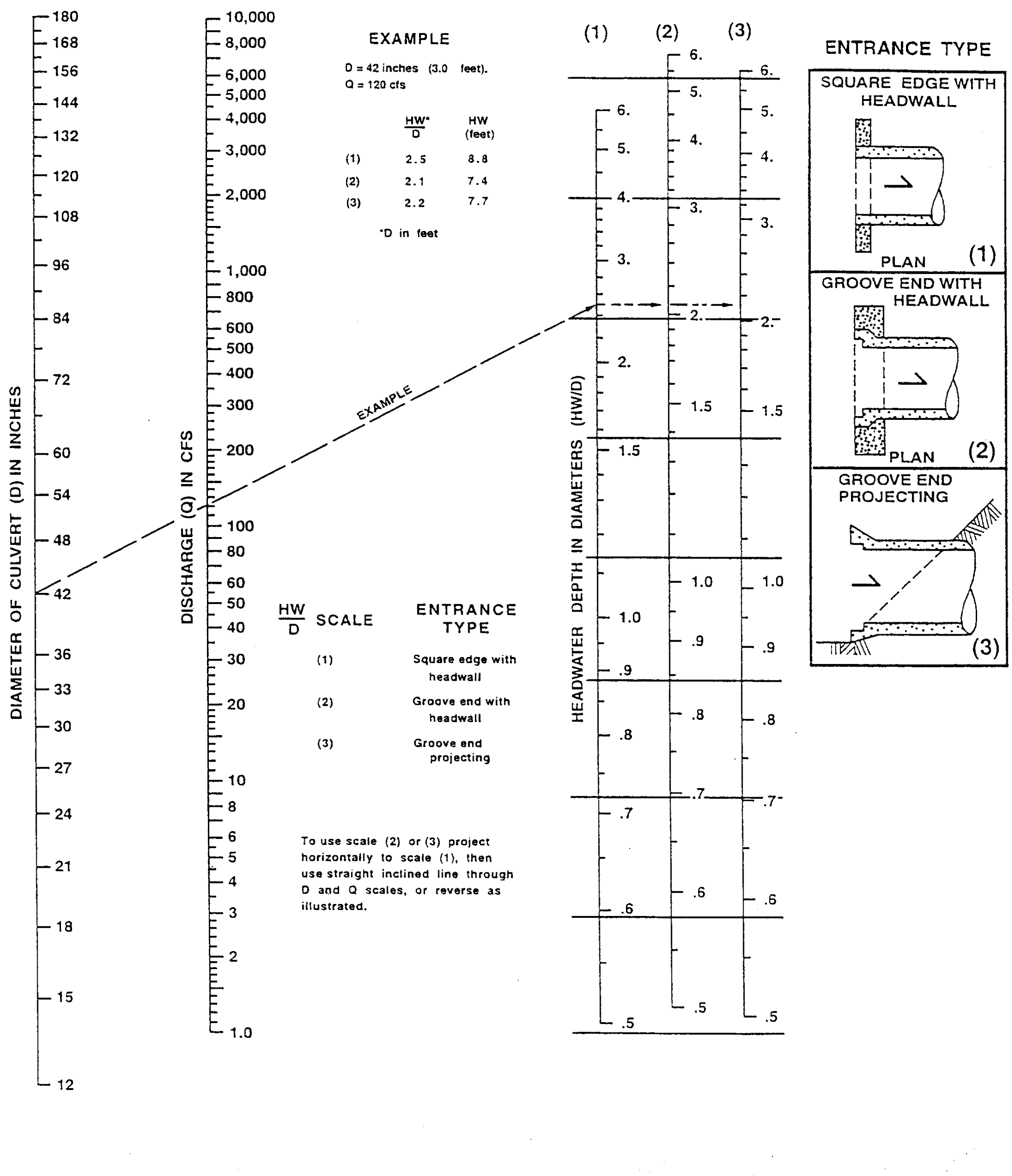
g) Adjust outlet pipe diameter as needed and repeat Steps (a) through (e).

TABLE 10. EQUIVALENCE: SCS SOIL TYPES AND TILL, OUTWASH OR WETLAND			
SCS Soil Type	**SCS Hydrologic Soil Group**	**Till, Outwash, or Wetland**	**Notes**
Alderwood (AgB, AgC, AgD)	C	Till	
Arents, Alderwood Material (AmB, AmC)	C	Till	
Arents, Everett Material (An)	B	Outwash	1
Beausite (BeC, BeD, BeF)	V	Till	2
Bellingham (Bh)	D	Till	3
Briscot (Br))	D	Till	3
Buckley (Bu)	D	Till	4
Earlmont (Ea)	D	Till	3
Edgewick (Ed)	C	Till	3
Everett (EvG, EvC, EvD, EwC)	A/B	Outwash	1
Indianola (InC, InA, InD)	A	Outwash	1
Kitsap (KpB, KpC, KpD)	C	Till	
Klaus (KsC)	C	Outwash	1
Neilton (NeC)	A	Outwash	1
Newberg (Ng)	B	Till	3
Nooksack (Nk)	C	Till	3
Norma (No)	D	Till	3
Orcas (Or)	D	Wetland	
Oridia (Os)	D	Till	3
Ovall (OvC, OvD, OvF)	C	Till	2
Pilchuck (Pc)	C	Till	3
Puget (Pu)	D	Till	3
Puyallup (Py)	B	Till	3
Ragnar (RaC, RaD, RaC, RaE)	B	Outwash	1
Renton (Re)	D	Till	3
Salal (Sa)	C	Till	3
Sammamish (Sh)	D	Till	3
Seattle (Sk)	D	Wetland	
Shalcar (Sm)	D	Till	3
Si (Sn)	C	Till	3
Snohomish (So, Sr)	D	Till	3
Sultan (Su)	C	Till	3
Tukwila (Tu)	D	Till	3
Woodinville (Wo)	D	Till	3

Notes:

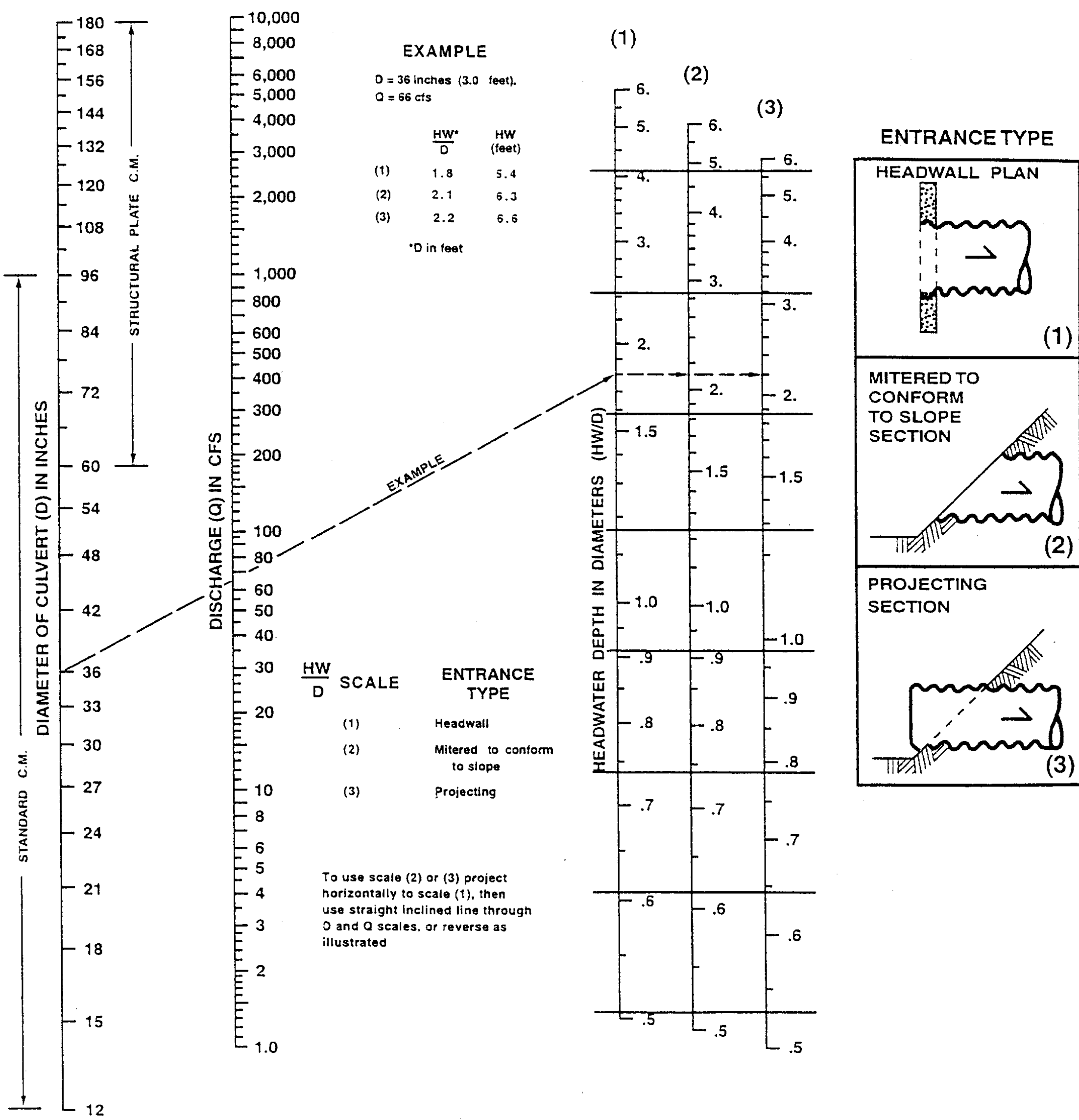
1. Where outwash soils are saturated or underlain at shallow dept (<5 feet) by glacial till, they should be treated as till soils.
2. These are bedrock soils, but calibration of HSPF by King County DNR shows bedrock soils to have similar hydrologic response to till soils.
3. These are alluvial soils, some of which are underlain by glacial till or have a seasonally high water table. In the absence of detail study, these soils should be treated as till soils.
4. Buckley soils are formed on the low-permeability Osceola mudflow. Hydrologic response is assumed to be similar to that of till soils.

FIGURE 16
HEADWATER DEPTH FOR SMOOTH INTERIOR PIPE CULVERTS WITH INLET CONTROL



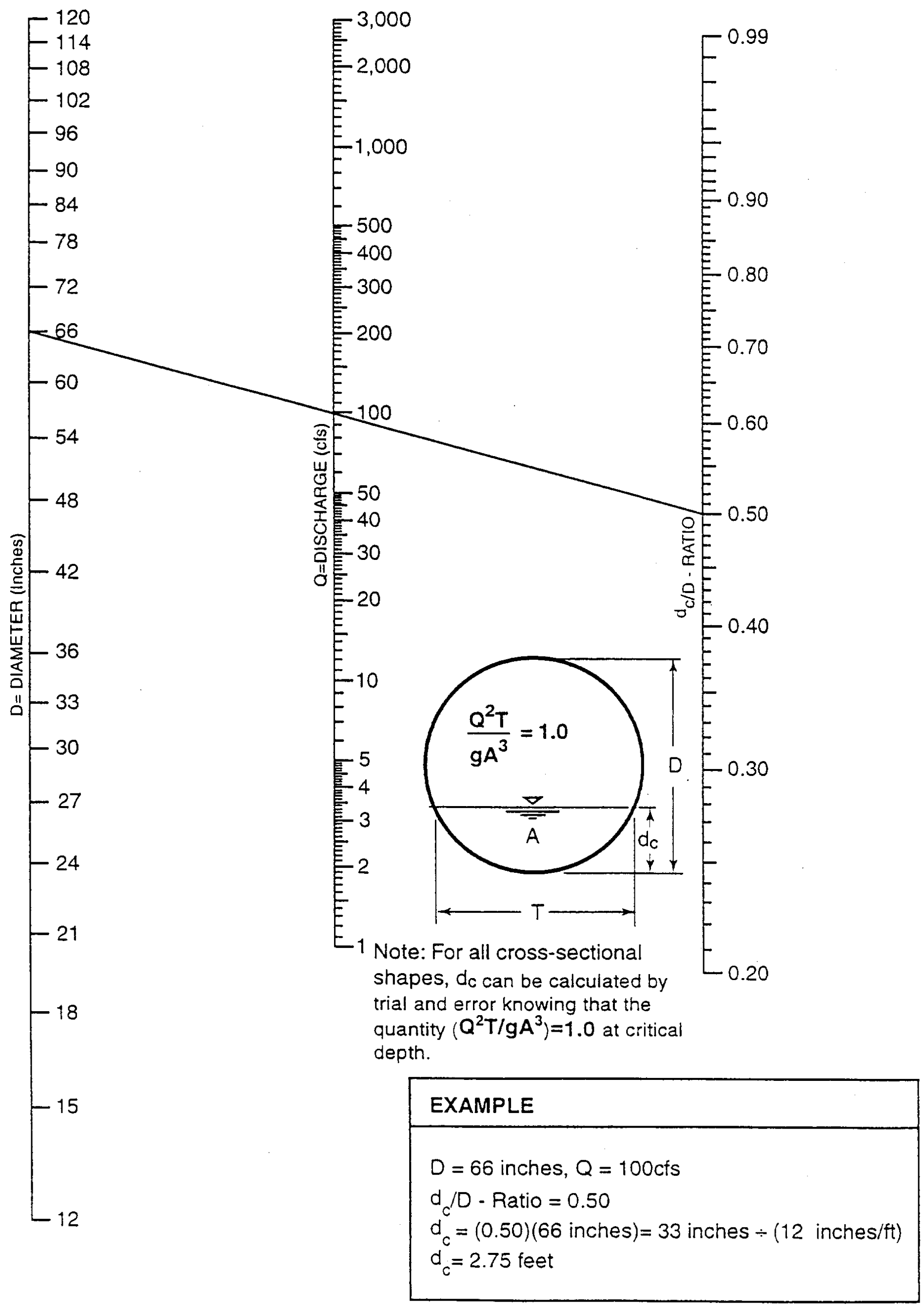
(Source: King County *Surface Water Design Manual*, 1998. Table 4.3.1.B)

FIGURE 17
HEADWATER DEPTH FOR CORRUGATED PIPE CULVERTS WITH INLET CONTROL



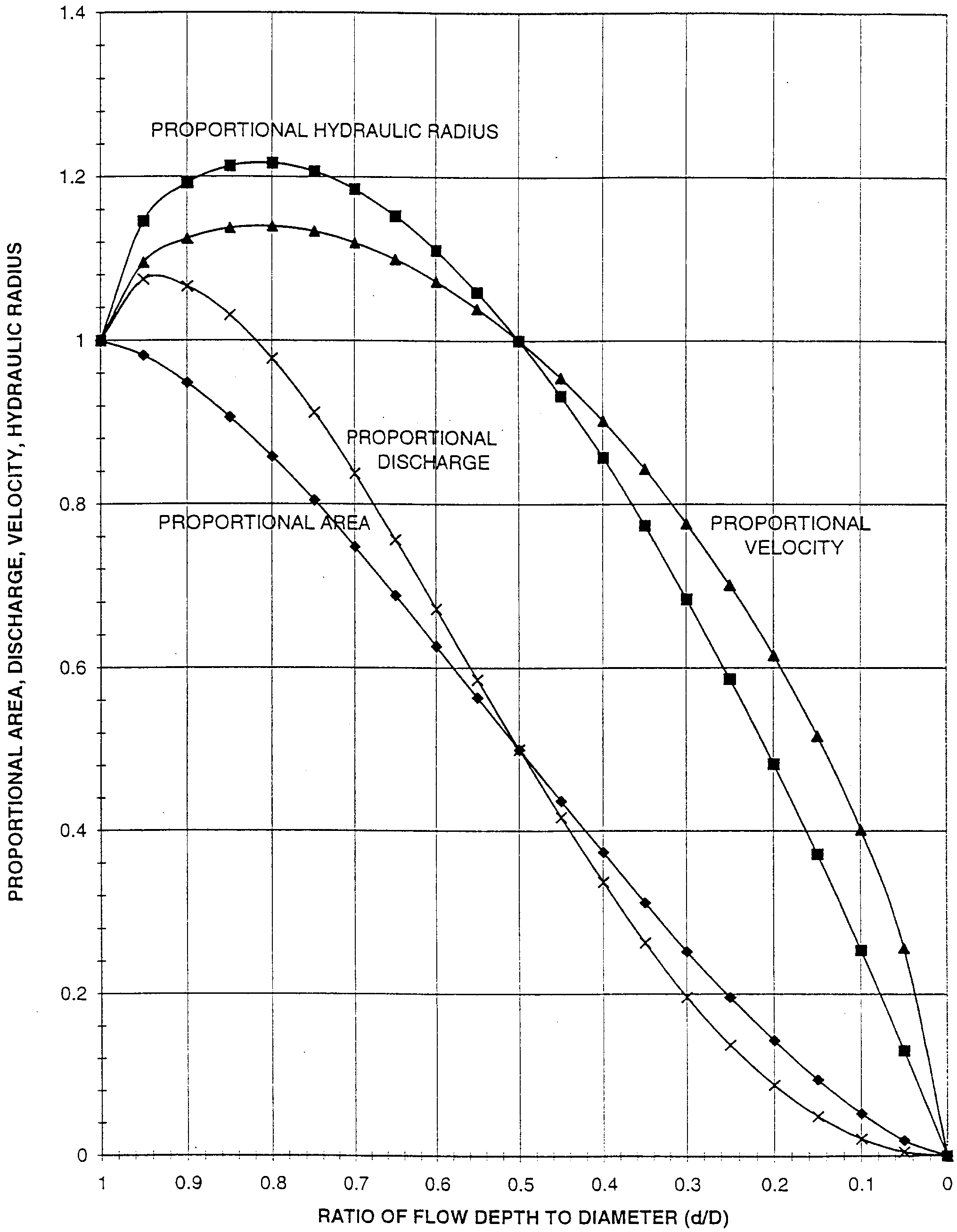
(Source: King County *Surface Water Design Manual*, 1998. Table 4.3.1.C)

FIGURE 18. CRITICAL DEPTH OF FLOW FOR CIRCULAR CULVERTS



(Source: King County *Surface Water Design Manual*, 1998. Table 4.3.1.F)

FIGURE 19. CIRCULAR CHANNEL RATIOS



(Source: King County *Surface Water Design Manual*, 1998. Table 4.2.1.G)

4.1.2 Design Criteria

General wetpond design criteria and concepts are shown in Figure 20 (p. 88).

❑ WETPOND

Wetpool Geometry

1. The wetpool shall be divided into **two cells** separated by a baffle or berm.[21] The first cell shall contain between 25% to 35% of the total wetpool volume. The baffle or berm volume shall not count as part of the total wetpool volume.

   Intent: The full-length berm or baffle promotes plug flow and enhances quiescence and laminar flow through as much of the entire water volume as possible. Use of a pipe and full-width manifold system to introduce water into the second cell is possible on a case-by-case basis if approved by DCLU.

2. Wetponds with wetpool volumes less than or equal to 4,000 cubic feet may be **single celled** (i.e., no baffle or berm is required).
3. **Sediment storage** shall be provided in the first cell. The sediment storage shall have a minimum depth of 1 foot.
4. The **minimum depth of the first cell** shall be 4 feet, exclusive of sediment storage requirements. The depth of the first cell may be greater than the depth of the second cell.
5. The **maximum depth of each cell** shall not exceed 8 feet (exclusive of sediment storage in the first cell). Pool depths of 3 feet or shallower (second cell) shall be planted with emergent wetland vegetation (see **Planting requirements**).
6. Inlets and outlets shall be placed to maximize the flow path through the facility. The **ratio of flow path length to width** from the inlet to the outlet shall be at least 3:1. The *flow path length* is defined as the distance from the inlet to the outlet, as measured at mid-depth. The *width* at mid-depth can be found as follows: width = (average top width + average bottom width)/2.
7. All inlets shall enter the first cell. If there are multiple inlets, the length-to-width ratio shall be based on the average flow path length for all inlets.

Berms, Baffles, and Slopes

1. A berm or baffle shall extend across the full width of the wetpool, and tie into the wetpond side slopes. If the berm embankments are greater than 4 feet in height, the berm **must be constructed by excavating a key** equal to 50% of the embankment cross-sectional height and width. This requirement may be waived if recommended by a geotechnical engineer for specific site conditions.[22]
2. The **top of the berm may extend** to the **water quality design water surface** or be one foot below the water quality design water surface. If at the water quality design water

[21] As used here, the term *baffle* means a vertical divider placed across the entire width of the pond, stopping short of the pond bottom. A berm is a vertical divider typically built up from the bottom, or if in a vault, connects all the way to the bottom.

[22] The geotechnical analysis must address situations in which one of the two cells is empty while the other remains full of water. These situations can occur, for example, during pump down of either cell for sediment removal, or when water from the second unlined cell percolates into the ground.

surface, berm side slopes must be 3H:1V. Berm side slopes may be steeper (up to 2:1) if the berm is submerged one foot.

Intent: Submerging the berm is intended to enhance safety by discouraging pedestrian access when side slopes are steeper than 3H:1V.

3. If good vegetation cover is not established on the berm, **erosion control measures** should be used to prevent erosion of the berm back-slope when the pond is initially filled.
4. The interior berm or baffle may be a **retaining wall** provided that the design is prepared and stamped by a licensed civil engineer. If a baffle or retaining wall is used, it shall be submerged one foot below the design water surface to discourage access by pedestrians.
5. Criteria for wetpond **side slopes** and **fencing** are given in Section 2.3 (p. 15).
6. Berm **embankments** shall meet the following criteria:
    a) Pond berm embankments higher than 6 feet shall require **design by a geotechnical engineer.**
    b) For berm embankments 6 feet or less, the **minimum top width** shall be 6 feet, or as recommended by a geotechnical engineer.
    c) Pond berm embankments must be **constructed on native consolidated soil** (or adequately compacted and stable fill soils analyzed by a geotechnical engineer) free of loose surface soil materials, roots, and other organic debris.
    d) Pond berm embankments greater than 4 feet in height must be **constructed by excavating a key** equal to 50% of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a geotechnical engineer.
    e) The berm embankment shall be **constructed of compacted soil** (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts, with the following soil characteristics per the United States Department of Agriculture's Textural Triangle: a minimum of 20% silt and clay, a maximum of 60% sand, a maximum of 60% silt, with nominal gravel and cobble content. *Note: In general, excavated glacial till is well suited for berm embankment material.*
    f) **Anti-seepage collars** must be placed on outflow pipes in berm embankments impounding water greater than 8 feet in depth at the design water surface.

Inlet and Outlet

See Figure 20 (p. 88) for details on the following requirements:

1. The **inlet** to the wetpond shall be **submerged** with the inlet pipe invert a minimum of two feet from the pond bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible.

    Intent: The inlet is submerged to dissipate energy of the incoming flow. The distance from the bottom is set to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.

2. An **outlet structure** shall be provided. A grated opening (jail house window) or a manhole with a cone grate (birdcage) may be used (see Figure 21). No sump is required in the outlet structure for wetponds not providing detention storage. The outlet structure receives flow from the pond outlet pipe. The grate or birdcage openings provide an

overflow route should the pond outlet pipe become clogged. Criteria 5 below specifies the sizing and position of the grate opening.

3. The **pond outlet pipe** (as opposed to the structure outlet) shall be back-sloped or have a turn-down elbow, and extend 1 foot below the water quality design water surface. *Note: A floating outlet, set to draw water from 1 foot below the water surface, is also acceptable if vandalism concerns are adequately addressed.*

   Intent: The inverted outlet pipe provides for trapping of oils and floatables in the wetpond.

4. The **pond outlet pipe** shall be sized, at a minimum, to pass the water quality design flow. *Note: The highest invert of the outlet pipe sets the* water quality ***design water surface*** *elevation*.

5. The **overflow** criteria for single-purpose wetponds are as follows:

   a) A **primary overflow** (usually a riser pipe within the control structure) must be provided to bypass the 100-year developed peak flow over or around the restrictor system. This assumes the facility will be full due to plugged orifices or high inflows; the primary overflow is intended to protect against breaching of a pond embankment (or overflows of the upstream conveyance system, in the case of a detention tank or vault). The design must provide controlled discharge directly into the downstream conveyance system or another acceptable discharge point.

   b) A **secondary inlet** to the control structure must be provided in ponds as an additional protection against overtopping should the inlet pipe to the control structure become plugged. A grated opening (“jailhouse window”) in the control structure manhole may function as a weir when used as a secondary inlet. *Note: The maximum circumferential length of this opening shall not exceed one-half the control structure circumference.* The “birdcage” overflow structure as shown in Figure 21 may also be used as a secondary inlet.

   c) The requirement for primary overflow as described above is satisfied by either the grated inlet to the outlet structure or by a birdcage above the pond outlet structure.

   d) The bottom of the grate opening in the outlet structure shall be set at or above the height needed to pass the water quality design flow through the pond outlet pipe (see page 71 for sizing details). *Note: The grate invert elevation sets the* ***overflow water surface*** *elevation.*

   e) In flow-through ponds, the grated opening shall be sized to pass the 100-year design flow.

6. An **emergency spillway** shall be provided and designed according to the following criteria.

   a) In addition to the above overflow requirements, ponds must have an emergency overflow spillway **sized to pass the 100-year developed peak flow** in the event of total control structure failure (e.g., blockage of the control structure outlet pipe) or extreme inflows. Emergency overflow spillways are intended to control the location of pond overtopping and direct overflows back into the downstream conveyance system or other acceptable discharge point.

b) Emergency overflow spillways must be provided for **ponds with constructed berms over 2 feet in height,** or for **ponds located on grades in excess of 5%.** As an option for ponds with berms less than 2 feet in height and located at grades less than 5%, emergency overflow may be provided by an **emergency overflow structure,** such as a manhole fitted with a birdcage. The emergency overflow structure must be designed to pass the 100-year developed peak flow, with a *minimum* 6 inches of freeboard, directly to the downstream conveyance system or another acceptable discharge point. Where an emergency overflow spillway would discharge to a steep slope, consideration should be given to providing an emergency overflow structure *in addition* to the spillway.

c) The emergency overflow spillway should be **armored with riprap**. The spillway shall be armored full width, beginning at a point midway across the berm embankment and extending downstream to where emergency overflows re-enter the conveyance system.

d) Design of emergency overflow spillways requires the analysis of broad-crested trapezoidal weir.

e) Maintenance access to the emergency overflow spillway must be provided.

7. A **gravity drain** for maintenance shall be provided if grade allows.

   a) The **drain invert** shall be at least 6 inches below the top elevation of the dividing berm or baffle. Deeper drains are encouraged where feasible, but must be no deeper than 18 inches above the pond bottom.

   Intent: to prevent highly sediment-laden water from escaping the pond when drained for maintenance.

   b) The drain shall be at least 8 inches (minimum) diameter and shall be controlled by a valve. Use of a shear gate is allowed only at the inlet end of a pipe located within an approved structure.

   Intent: Shear gates often leak if water pressure pushes on the side of the gate opposite the seal. The gate should be situated so that water pressure pushes toward the seal.

   Intent: It is anticipated that sediment removal will only be needed for the first cell in the majority of cases. The gravity drain is intended to allow water from the first cell to be drained to the second cell when the first cell is pumped dry for cleaning.

8. Operational access to the valve shall be provided to the finished ground surface.

   a) The valve location shall be accessible and well-marked with one foot of paving placed around the box. It must also be protected from damage and unauthorized operation.

   b) A valve box is allowed to a maximum depth of 5 feet without an access manhole. If over 5 feet deep, an access manhole or vault is required.

9. All metal parts shall be corrosion-resistant. Galvanized materials are discouraged where substitutes are available.

Access and Setbacks

1. The location of the pond relative to site constraints (e.g., buildings, property lines, etc.) shall meet the following criteria:

a) A setback of 5 feet from the **toe of the exterior slope** of the tract or property line is recommended.

b) The tract or property line on a pond cut slope shall be setback 5 feet from the **emergency overflow water surface.**

c) The pond water surface at the outlet invert elevation shall be setback 100 feet from **existing septic system drainfields.** This setback may be reduced with written approval of the Seattle-King County Department of Public Health.

2. Access and maintenance **roads** shall be provided and designed according to the requirements described below. Access and maintenance roads shall extend to both the wetpond inlet and outlet structures. An access ramp (7H minimum:1V) shall be provided to the bottom of the first cell unless all portions of the cell can be reached and sediment loaded from the top of the pond.

   a) **Maintenance access road(s)** shall be provided to the control structure and other drainage structures associated with the pond (e.g., inlet or bypass structures). Manhole and catch basin lids must be in or at the edge of the access road and at least three feet from a property line.

   b) An **access ramp** is required for removal of sediment with a trackhoe and truck. The ramp should extend to the pond bottom if the pond bottom is greater than 1,500 square feet (measured without the ramp) and it may end at an elevation of 4 feet above the pond bottom, if the pond bottom is less than 1,500 square feet (measured without the ramp).

   Intent: On large, deep ponds, truck access to the pond bottom via an access ramp is necessary so loading can be done in the pond bottom. On small deep ponds, the truck can remain on the ramp for loading. On small shallow ponds, a ramp to the bottom may not be required if the trackhoe can load a truck parked at the pond edge or on the internal berm of a wetpond or combined pond (trackhoes can negotiate interior pond side slopes).

   c) The **internal berm** of a wetpond or combined detention and wetpond may be used for access if it is no more than 4 feet above the first wetpool cell, if the first wetpool cell is less than 1,500 square feet (measured without the ramp), and if it is designed to support a loaded truck, considering the berm is normally submerged and saturated.

   d) **Access ramps** shall meet the requirements for design and construction of access roads specified below.

   e) All control structures shall have round, solid **locking lids** with 5/8-inch diameter allen head cap screws.

   f) Access shall be limited by a double-posted gate if a fence is required, or by **bollards—**that is, two fixed bollards on each side of the access road and two removable bollards equally located between the fixed bollards.

3. If the **dividing berm** is also **used for access**, it must be built to sustain loads of up to 80,000 pounds.

Design of Access Roads

Access roads shall meet the following design criteria:

1. **Maximum grade** shall be 15%.

2. Outside **turning radius** shall be a *minimum* of 40 feet.
3. **Fence gates** shall be located only on straight sections of the road.
4. Access roads shall be 10 feet in **width**.
5. A **paved apron** shall be provided where access roads connect to paved public roadways.
6. Access roads shall be constructed with an asphalt or gravel surface, or modular grid pavement.

Signage

1. Signage meeting the specifications below shall be placed for maximum visibility from adjacent streets, sidewalks, and paths.

a)	Size:	48 inches by 24 inches
b)	Material:	0.125-gauge aluminum
c)	Face:	Non-reflective vinyl or 3 coats outdoor enamel (sprayed).
d)	Lettering:	Silk screen enamel where possible, or vinyl letters.
e)	Colors:	Beige background with teal letters.
f)	Type Face:	Helvitica condensed (or similar). Title: 3 inches; Sub-Title: 1-1/2 inches; Text: 1 inch.
g)	Installation:	Secure to chain link fence if available. Otherwise, install on posts, mounted atop gravel bed, installed in 30-inch concrete filled post holes. Top of sign no higher than 42 inches from ground surface.
h)	Placement:	Place sign in direction of primary visual or physical access. Do not block any access road. Do not place within 6 feet of structural facilities (e.g., maintenance holes, spillways, pipe inlets).
i)	Text:	Title – "Stormwater Pond" Sub-Title – "This pond is in our care" Text – "Runoff is held here after storms. It is released slowly or stored until the next storm, when it is replaced by incoming floes. This helps prevent downstream flooding and erosion , and helps clean the water. For more information or to report littering, vandalism or other problems, call [provide management name and contact phone number(s)]"
j)	If lined facility:	If facility has a liner to restrict infiltration of stormwater, the following note must be added to the face of the sign: "This facility is lined to protect groundwater quality." In addition, the back of the sign shall include information indicating the extent of the lining, the liner material used, the liner thickness (if clay or till), and the type and distance of the marker above the line (if a geomembrane). This information need only be readable by someone standing at arms-length from the sign.

Planting Requirements

1. Exposed earth on the pond bottom and interior side slopes shall be sodded or seeded with an appropriate seed mixture. All remaining areas of the tract must either be planted with grass or be landscaped and mulched with a 4-inch cover of hog fuel or shredded wood mulch.[23] Information on landscaping is provided in the next section.

   If the second cell of the wetpond is 3 feet or shallower, the bottom area shall be planted with emergent wetland vegetation. See Table 12 (p. 87) for recommended emergent wetland plant species for wetponds. **Intent:** Planting of shallow pond areas helps to stabilize settled sediment and prevent resuspension.

   Note: The recommendations in Table 18 *are for western Washington only. Local knowledge should be used to adapt this information if used in other areas.*

2. Cattails (Typha latifolia) are not recommended because they tend to crowd out other species, and the dead shoots need to be removed to prevent oxygen depletion in the wetpool.

3. To reduce phosphorus input, shrubs that form a dense cover should be planted on slopes above the water quality design water surface on at least three sides. For banks that are berms, no planting is allowed if the berm is regulated by dam safety requirements (see [reference Paragraph in "Side Slopes, Fencing & Embankment]) . The purpose of planting is to discourage waterfowl use of the pond and to provide shading.[24] Some suitable trees and shrubs include vine maple (*Acer circinatum*), wild cherry (*Prunus emarginata*), red osier dogwood (*Cornus stolonifera*), California myrtle (*Myrica californica*), Indian plum (*Oemleria cerasiformis*), and Pacific yew (*Taxus brevifolia*) as well as numerous ornamental species.

Landscaping

Landscaping is encouraged, but not required for most stormwater tract areas (see below for areas not to be landscaped). However, if provided, landscaping must adhere to the criteria which follow so as not to hinder maintenance operations.

If landscaping is proposed, the following requirements shall apply:

1. **No trees or shrubs may be planted within 10 feet of inlet or outlet pipes** or manmade drainage structures such as spillways or flow spreaders. Species with roots that seek water, such as willow or poplar, should be avoided within 50 feet of pipes or manmade structures.

2. **Planting is restricted on berms that impound water** either permanently or temporarily during storms. *Note: This restriction does not apply to cut slopes that form pond banks, only to berms.*

   a) Trees or shrubs may not be planted on portions of water-impounding berms taller than four feet high. Only grasses may be planted on berms taller than four feet.

      Intent: Grasses allow unobstructed visibility of berm slopes for detecting potential dam safety problems, such as animal burrows, slumping, or fractures in the berm.

[23] Shredded wood mulch is made from shredded tree trimmings, usually from trees cleared on site. It must be free of garbage and weeds and may not contain excessive resin, tannin, or other material detrimental to plant growth.

[24] Waterfowl are believed to limit use of areas where their view of predator approach paths is blocked. Some suitable native shrubs include vine maple, Indian plum, bitter cherry, red osier dogwood, cascara, and red elderberry. Ornamental hedge plants such as English laurel, privet and barberry are also good choices.

b) Trees planted on portions of water-impounding berms less than 4 feet high must be small, not higher than 20 feet mature height, and have a fibrous root system. Table 11 gives some examples of trees with these characteristics.

Intent: These trees reduce the likelihood of blow-down trees, or the possibility of channeling or piping of water through the root systems, which may contribute to dam failure on berms that retain water.

3. All landscape material, including grass, must be **planted in good topsoil.** Native underlying soils may be suitable for planting if amended with 4 inches of well-rotted compost tilled into the subgrade. Compost used should meet Ecology publication 94-38 specifications for Grade A compost quality.
4. Soil in which **trees or shrubs** are planted may require additional enrichment or additional compost top-dressing. Consult a landscape professional or arborist for site-specific recommendations.
5. For a naturalistic effect, as well as ease of maintenance, trees or shrubs should be planted in clumps to form “landscape islands” rather than evenly spaced.
6. The **landscaped islands** should be a minimum of six feet apart, and if set back from fences or other barriers, the setback distance should also be a minimum of six feet. Where tree foliage extends low to the ground, the six feet of setback should be counted from the outer drip line of the trees (estimated at maturity).

   Intent: This setback allows a 6-foot wide mower to pass around and between clumps.
7. Evergreen trees and other trees that produce relatively little leaf-fall (such as Oregon ash, mimosa, or locust) are preferred in areas draining to the pond.
8. Trees should be set back so that branches do not extend over the pond (to prevent leaf-drop into the water).
9. Drought tolerant species are recommended.

TABLE 11. SMALL TREES AND SHRUBS WITH FIBROUS ROOTS

Small Trees/High Shrubs	Low Shrubs
Red twig dogwood (*Comus Stolonifera*)*	Snowberry (*Symphoricarpus albus*)*
Serviceberry (*Amelanchier ainifolia*)*	Salmonberry (*Rubus spectabillis*)*
Strawberry tree (*Arbutus unedo*)	Rosa rugosa (avoid spreading varieties)
Highbush cranberry (*Vaccinium opulus*)	Rock rose (*Cistus* spp.)
Blueberry (*Vaccinium* spp.)	Ceanothus spp. (choose hardier varieties)
Filbert (*Corylus comuta*, others)*	New Zealand flax (*Phormium penax*)
Fruit trees on dwarf rootstock	Ornamental grasses (e.g., *Miscanthis, Pennisetum*)
Rhododendron (native and ornamental varieties)	
* Native Species	

Recommended Design Features

The following design features should be incorporated into the wetpond design where site conditions allow:

1. For wetpool depths in excess of 6 feet, it is recommended that some form of **recirculation** be provided in the summer, such as a fountain or aerator, to prevent stagnation and low dissolved oxygen conditions.
2. A flow length-to-width ratio greater than the 3:1 minimum is desirable. If the ratio is 4:1 or greater, and a gravity drain for maintenance is provided 12 to 18 inches from the pond bottom, then the **dividing berm is not required**, and the pond may consist of one cell rather than two.
3. A **tear-drop shape**, with the inlet at the narrow end, rather than a rectangular pond is preferred since it minimizes dead zones caused by corners.
4. A small amount of **base flow** is desirable to maintain circulation and reduce the potential for low oxygen conditions during late summer.
5. Evergreen or columnar deciduous **trees along the west and south sides** of ponds are recommended to reduce thermal heating, except that no trees or shrubs may be planted on berms meeting the criteria of dams regulated for safety. In addition to shade, trees and shrubs also discourage waterfowl use and the attendant phosphorus enrichment problems they cause. Trees should be set back so that the branches will not extend over the pond.

   Intent: Evergreen trees or shrubs are preferred to avoid problems associated with leaf drop. Columnar deciduous trees (e.g., hornbeam, Lombardy poplar, etc.) typically have fewer leaves than other deciduous trees.
6. The **number of inlets** to the facility should be limited; ideally there should be only one inlet. The flow path length should be maximized from inlet to outlet for all inlets to the facility.
7. The **access and maintenance road** could be extended along the full length of the wetpond and could double as play courts or picnic areas. Placing finely ground bark or other natural material over the road surface would render it more pedestrian friendly.
8. Signage discouraging **feeding of waterfowl** is recommended.
9. The following design features should be incorporated to **enhance aesthetics** where possible:
   a) Provide pedestrian access to shallow pool areas enhanced with emergent wetland vegetation. This allows the pond to be more accessible without incurring safety risks.
   b) Provide side slopes that are sufficiently gentle to avoid the need for fencing (3:1 or flatter).
   c) Create flat areas overlooking or adjoining the pond for picnic tables or seating that can be used by residents. Walking or jogging trails around the pond are easily integrated into site design.
   d) Include fountains or integrated waterfall features for privately maintained facilities.
   e) Provide visual enhancement with clusters of trees and shrubs. On most pond sites, it is important to amend the soil before planting since ponds are typically placed well below the native soil horizon in very poor soils. Make sure dam safety restrictions against planting do not apply.

f) Orient the pond length along the direction of prevailing summer winds (typically west or southwest) to enhance wind mixing.[25]

Construction Considerations

1. Sediment that has accumulated in the pond must be removed after construction in the drainage area of the pond is complete (unless used for a liner—see Construction Criterion 2 below). If no more than 12 inches of sediment have accumulated after plat construction, cleaning may be left until after building construction is complete. In general, sediment accumulation from stabilized drainage areas is not expected to exceed an average of 4 inches per year in the first cell. If sediment accumulation is greater than this amount, it should be assumed to be from construction unless it can be shown otherwise.
2. Sediment that has accumulated in the pond at the end of construction may be used as a liner in excessively drained soils if the sediment meets the criteria for low permeability or treatment liners defined in Section 2.4 (p. 17) and in keeping with guidance given in Table 3 (p.18). Sediment used for a soil liner must be graded to provide uniform coverage and thickness.

Maintenance Considerations

1. The pond should be inspected annually. Floating debris and accumulated petroleum products should be removed as needed, but at least annually.
2. Site vegetation should be trimmed as necessary to keep the pond free of leaves and to maintain the aesthetic appearance of the site. Slope areas that have become bare should be revegetated and eroded areas should be regraded prior to being revegetated.
3. Sediment should be removed when the 1-foot sediment zone is full plus 6 inches. Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.

Water drained or pumped from ponds prior to sediment removal may be discharged to storm drains if it is not excessively turbid (i.e., if water appears translucent when held to light) and if floatable debris and visual petroleum sheen are removed. Excessively turbid water (i.e., water appears opaque when held to light) should be discharged only after the solids have been settled and removed.

[25] Wind moving over the surface of standing water can often induce some mixing of surface and near-surface water, replenishing oxygen and reducing stagnant conditions. If the pond is aligned with the prevailing wind direction, this effect can be maximized.

TABLE 12. EMERGENT WETLAND PLANT SPECIES RECOMMENDED FOR WETPONDS			
Species	**Common Name**	**Notes**	**Maximum Depth**
INUNDATION TO 1 FOOT			
Agrostis exarata[1]	Spike bent grass	Prairie to coast	to 2 feet
Carex stipata	Sawbeak sedge	Wet ground	
Eleocharis palustris	Spike rush	Margins of ponds, wet meadows	to 2 feet
Glyceria occidentalis	Western mannagrass	Marshes, pond margins	to 2 feet
Juncus effusus	Soft rush	Wet meadows, pastures, wetland margins	to 2 feet
Juncus tenuis	Slender rush	Wet soils, wetland margins	
Oenanthe sarmentosa	Water parsley	Shallow water along stream and pond margins; needs saturated soils all summer	
Scirpus atrocinctus (formerly S. cyperinus)	Woolgrass	Tolerates shallow water; tall clumps	
Scirpus microcarpus	Small-fruited bulrush	Wet ground to 18 inches depth	18 inches
Sagittaria latifolia	Arrowhead		
INUNDATION 1 TO 2 FEET			
Agrostis exarata[1]	Spike bent grass	Prairie to coast	
Alisma plantago-aquatica	Water plantain		
Eleocharis palustris	Spike rush	Margins of ponds, wet meadows	
Glyceria occidentalis	Western mannagrass	Marshes, pond margins	
Juncus effusus	Soft rush	Wet meadows, pastures, wetland margins	
Scirpus microcarpus	Small-fruited bulrush	Wet ground to 18 inches depth	18 inches
Sparganium emmersum	Bur reed	Shallow standing water, saturated soils	
INUNDATION 1 TO 3 FEET			
Carex obnupta	Slough sedge	Wet ground or standing water	1.5 to 3 feet
Beckmania syzigachne[1]	Western sloughgrass	Wet prairie to pond margins	
Scirpus acutus[2]	Hardstem bulrush	Single tall stems, not clumping	to 3 feet
Scirpus validus[2]	Softstem bulrush		
INUNDATION GREATER THAN 3 FEET			
Nuphar polysepalum	Spatterdock	Deep water	3 to 7.5 feet
Nymphaea odorata[1]	White waterlily	Shallow to deep ponds	to 6 feet

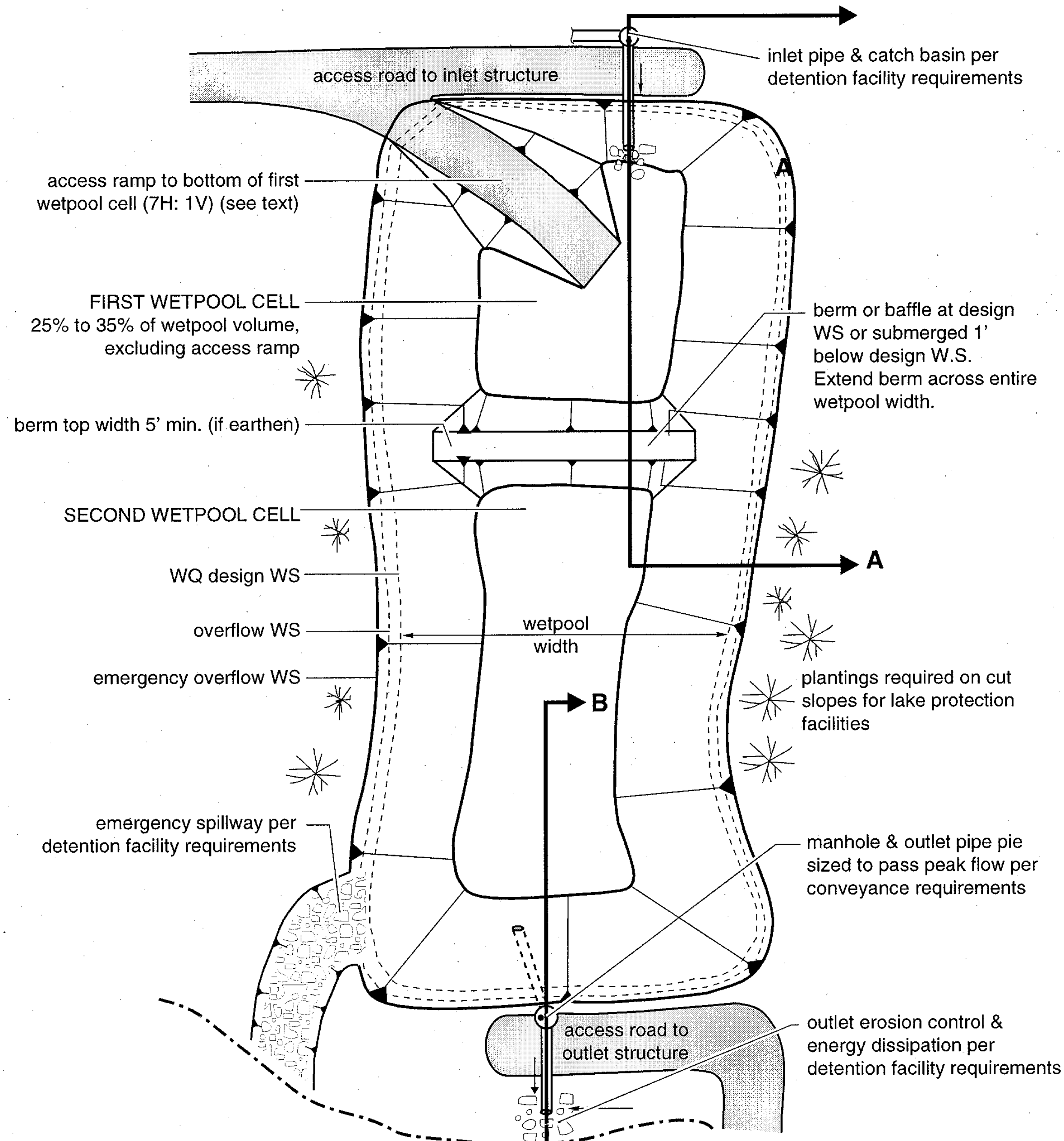
Notes:

[1] Non-native species. *Beckmania syzigachne* is native to Oregon. Native species are preferred.

[2] *Scirpus* tubers must be planted shallower for establishment, and protected from foraging waterfowl until established. Emerging aerial stems should project above water surface to allow oxygen transport to the roots.

Primary sources: Municipality of Metropolitan Seattle, *Water Pollution Control Aspects of Aquatic Plants*, 1990. Hortus Northwest, *Wetland Plants for Western Oregon*, Issue 2, 1991. Hitchcock and Cronquist, *Flora of the Pacific Northwest*, 1973.

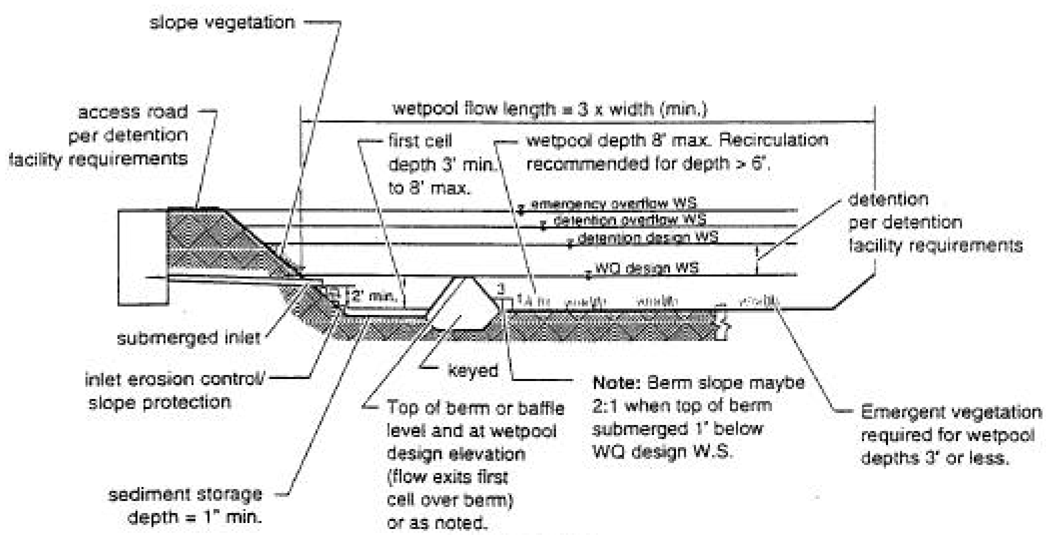
FIGURE 20. TYPICAL WETPOND



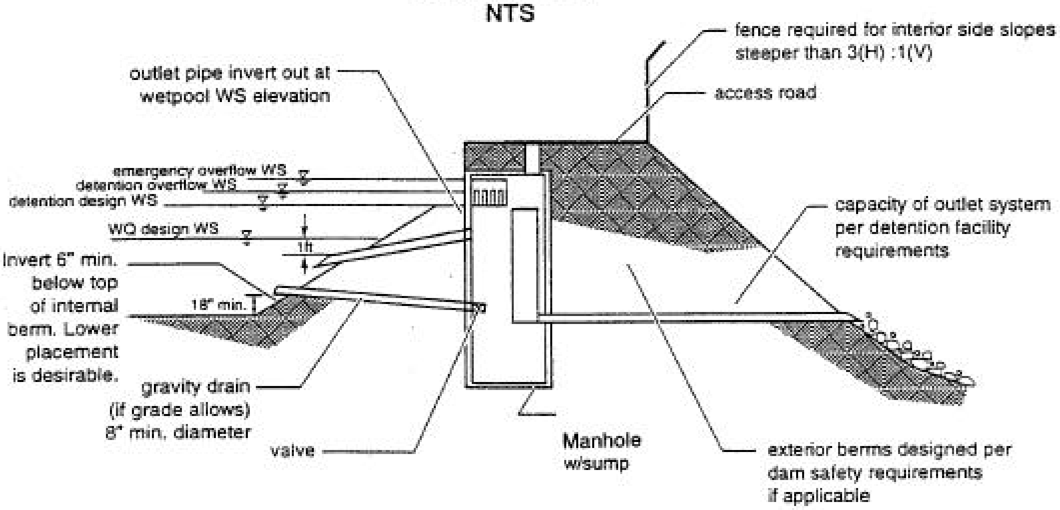
NOTE: Berm not required for ponds with length to width ratio ≥ 4:1 or if volume less than 4000 c.f.

PLAN VIEW
NTS

FIGURE 20. TYPICAL WETPOND (*CONTINUED*)

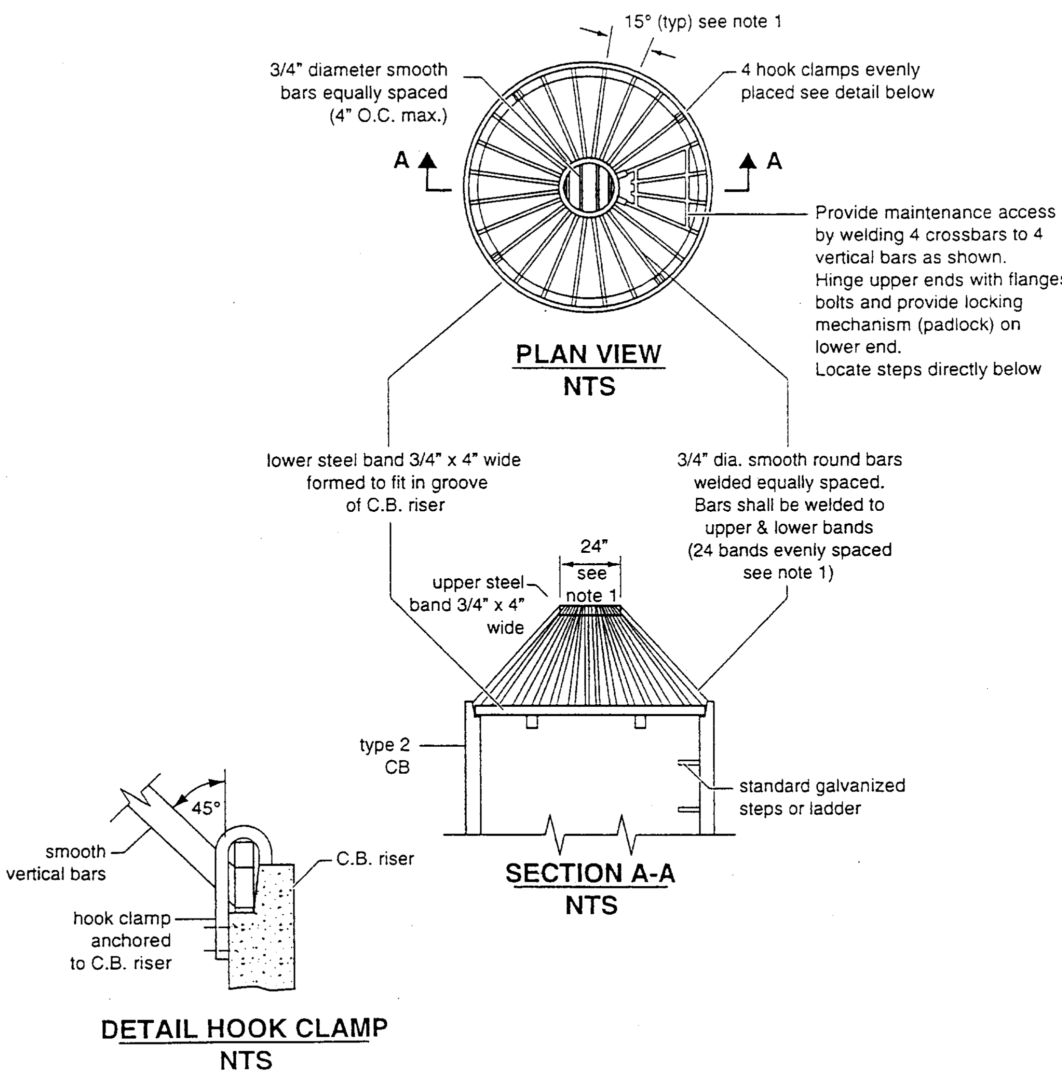


SECTION A-A
NTS



SECTION B-B
NTS

FIGURE 21. OVERFLOW STRUCTURE



NOTES:

1. Dimensions are for illustration on 54" diameter CB For different diameter CB's adjust to maintain 45° angle on "vertical" bars and 7" o.c. maximum spacing of bars around lower steel band.
2. Metal parts must be corrosion resistant; steel bars must be galvanized.
3. This debris barrier is also recommended for use on the inlet to roadway cross-culverts with high potential for debris collection (except on type 2 streams)
4. This debris barrier is for use outside of road right-of-way only.

4.2 WETVAULTS

A *wetvault* is an underground structure similar in appearance to a detention vault, except that a wetvault has a permanent pool of water which dissipates energy and improves the settling of particulate pollutants (see examples of wetvault details, Figure 22, on page 96).

Applications and Limitations

A wetvault may be used in any type or size of development. However, it is most practical in relatively small catchments (less than 10 acres of impervious surface) with high land values because vaults are relatively expensive. Combined detention and wetvaults are allowed; see Section 4.4 (p. 104). A wetvault is believed to be ineffective in removing dissolved pollutants such as soluble phosphorus or metals such as copper. There is also concern that oxygen levels will decline, especially in warm summer months, because of limited contact with air and wind. However, the extent to which this potential problem occurs has not been documented.

4.2.1 Methods of Analysis

As with wetponds, the primary design factor that determines the removal efficiency of a wetvault is the volume of the wetpool in relationship to the volume of runoff (V_r) from the mean annual storm. The larger the volume, the higher the potential for pollutant removal. Performance is also improved by avoiding dead zones (like corners) where little exchange occurs, using large length-to-width ratios, dissipating energy at the inlet, and ensuring that flow rates are uniform to the extent possible and not increased between cells.

The methods of analysis for the wetvault are **identical to the methods of analysis for the wetpond**. Follow the procedure specified in Section 4.1 to determine the wetpool volume for the wetvault.

4.2.2 Design Criteria

In addition to their water quality function, wetvaults may serve a conveyance function, passing flows above the water quality design flow through to the downstream drainage system. When used to convey these flows, vaults must meet the conveyance requirements specified in Chapter 4.

Typical design details and concepts for wetvaults are shown in Figure 22 (p. 96).

Wetpool Geometry

Same as specified for **wetponds** (see Section 4.1.2, p. 77) except for the following **two modifications:**

1. **Criterion 3:** The **sediment storage** in the first cell shall be an average of 1 foot. Because of the v-shaped bottom, the depth of sediment storage needed above the bottom of the side wall is roughly proportional to vault width according to the schedule below:

Vault Width	Sediment Depth (from bottom of side wall)
15'	10"
20'	9"
40'	6"
60'	4"

2. **Criterion 5:** The second cell shall be a minimum of 3 feet deep since planting cannot be used to prevent resuspension of sediment in shallow water as it can in open ponds.

Vault Structure

1. Wetvaults shall be designed as flow-through systems.
2. The vault shall be separated into two cells by a **wall** or a **removable baffle**.[26] If a **wall** is used, a 5 foot by 10 foot removable maintenance access must be provided for both cells. If a removable baffle is used, the following criteria apply:
   a) The baffle shall extend from a minimum of 1 foot above the water quality design water surface to a minimum of 1 foot below the invert elevation of the inlet pipe.
   b) The lowest point of the baffle shall be a minimum of 2 feet from the bottom of the vault, and greater if feasible.
3. If the vault is less than 2,000 cubic feet (inside dimensions), or if the length-to-width ratio of the vault pool is 5:1 or greater the **baffle or wall** may be omitted and the vault may be one-celled.
4. The two cells of a wetvault should not be divided into additional subcells by **internal walls**. If internal structural support is needed, it is preferred that post and pier construction be used to support the vault lid rather than walls. Any walls used within cells must be positioned so as to lengthen, rather than divide, the flow path.

   Intent: Treatment effectiveness in wetpool facilities is related to the extent to which plug flow is achieved and short-circuiting and dead zones are avoided. Structural walls placed within the cells can interfere with plug flow and create significant dead zones, reducing treatment effectiveness.
5. The bottom of the first cell shall be sloped toward the access opening. Slope should be between 0.5% (minimum) and 2% (maximum). The second cell may be level (longitudinally) sloped toward the outlet, with a high point between the first and second cells.
6. The **vault bottom** shall slope laterally a minimum of 5% from each side towards the center, forming a broad "v" to facilitate sediment removal. *Note: More than one "v" may be used to minimize vault depth.*

   Exception*:* The vault bottom may be flat if **removable panels** are provided over the entire vault. Removable panels shall be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel.
7. The highest point of a **vault bottom** must be at least 6 inches below the outlet elevation to provide for sediment storage over the entire bottom.
8. Provision for passage of flows should the outlet plug shall be provided.
9. Wetvaults may be constructed using **arch culvert sections** provided the top area at the water quality design water surface is, at a minimum, equal to that of a vault with vertical walls designed with an average depth of 6 feet.

   Intent: To prevent decreasing the surface area available for oxygen exchange.
10. Where pipes enter and leave the vault below the water quality design water surface, they shall be **sealed** using a non-porous, non-shrinking grout.

[26] As used here, the term *baffle* means a divider that does not extend all the way to the bottom of the vault, or if a bottom baffle, does not extend all the way to the top of the water surface. A *wall* is used here to mean a divider that extends all the way from near the water surface to the bottom of the vault.

Materials and Structural Stability

1. Structural reinforced concrete must be used for all vaults. All construction joints must be provided with water stops.

2. All vaults shall meet structural requirements for overburden support and traffic loading. Cast-in-place wall sections shall be designed as retaining walls. Vaults shall be placed on stable bedding. Vaults shall not be allowed in fill slopes, unless analyzed in a geotechnical report for stability and constructability.

Inlet and Outlet

1. The **inlet** to the wetvault shall be submerged with the inlet pipe invert a minimum of 3 feet from the vault bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible.

   Intent: The submerged inlet is to dissipate energy of the incoming flow. The distance from the bottom is to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.

2. Unless designed as an off-line facility, the capacity of the **outlet pipe** and available head above the outlet pipe shall be designed to convey the 100-year design flow for developed site conditions without overtopping the vault. The available head above the outlet pipe must be a minimum of 6 inches.

3. The outlet pipe shall be back-sloped or have tee section, the lower arm of which should extend 1 foot below the water quality design water surface to provide for trapping of oils and floatables in the vault.

4. A **gravity drain** for maintenance shall be provided if grade allows.

   a) The gravity drain should be as low as the site situation allows; however, the **invert** shall be no lower than the average sediment storage depth. At a minimum, the invert shall be 6 inches above the base elevation of the vault side walls.

      Intent: This placement prevents highly sediment-laden water from escaping when the vault is drained for maintenance. A lower placement is allowed than for wetponds since the v-shaped vault bottom will capture and retain additional sediments.

   b) The drain shall be 8 inches (minimum) diameter and shall be controlled by a valve. Use of a shear gate is allowed only at the inlet end of a pipe located within an approved structure.

      Intent: Shear gates often leak if water pressure pushes on the side of the gate opposite the seal. The gate should be situated so that water pressure pushes toward the seal.

   c) Operational access to the valve shall be provided to the finished ground surface. The valve location shall be accessible and well marked with one foot of paving placed around the box. It must also be protected from damage and unauthorized operation.

   d) If not located in the vault, a valve box is allowed to a maximum depth of 5 feet without an access manhole. If over 5 feet deep, an access manhole is required.

Access Requirements

1. **Access** shall be provided over *both* the inlet pipe and outlet structure. Access openings shall be positioned a maximum of 50 from any location within the tank; additional access

points may be required on large vaults. If more than one "v" is provided in the vault floor, access to each "v" must be provided.

2. For vaults with **greater than 1,250 square feet of floor area,** a 5 feet by 10 feet removable panel shall be provided over the inlet pipe (instead of a standard frame, grate and solid cover). Alternatively, a separate access vault may be provided.
3. All **access openings,** except those covered by removable panels, shall have round, solid **locking lids,** or 3-foot square, locking diamond plate covers.
4. **Internal structural walls** of large vaults shall be provided with separate access risers or openings sufficient for maintenance access between cells. The openings shall be sized and situated to allow access to the maintenance "v" in the floor.
5. The **minimum internal height** shall be 7 feet from the highest point of the vault floor (not sump), and the **minimum width** shall be 4 feet.

   Exceptions:

   - Concrete vaults may be a minimum 3 feet in height and width if used as tanks with access manholes at each end, and if the width is no larger than the height.
   - The minimum internal height requirements may be waived for any areas covered by removable panels.
6. Vaults must comply with the **OSHA confined space requirements,** which include clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser(s) just under the access lid.
7. A minimum of 50 square feet of **grate** shall be provided over the second cell. For vaults in which the surface area of the second cell is greater than 1,250 square feet, 4% of the top shall be grated. This requirement may be met by one grate or by many smaller grates distributed over the second cell area. *Note: a grated access door can be used to meet this requirement.*

   Intent: The grate allows air contact with the wetpool in order to minimize stagnant conditions which can result in oxygen depletion, especially in warm weather.

Access Roads

1. Access roads are required to the access panel (if applicable), the control structure, and at least one access point per cell.

Recommended Design Features

The following design features should be incorporated into wetvaults where feasible, but they are not specifically required:

1. The floor of the second cell should slope toward the outlet for ease of cleaning.
2. The **inlet and outlet** should be at opposing corners of the vault to increase the flow path.
3. A **flow length-to-width** ratio greater than 3:1 minimum is desirable.
4. **Lockable grates** instead of solid manhole covers are recommended to increase air contact with the wetpool.
5. **Galvanized materials** should be avoided whenever possible.

6. The **number of inlets** to the wetvault should be limited, and the flow path length should be maximized from inlet to outlet for all inlets to the vault.

Construction Considerations

Sediment that has accumulated in the vault must be removed after construction in the drainage area is complete. If no more than 12 inches of sediment have accumulated after the infrastructure is built, cleaning may be left until after building construction is complete. In general, sediment accumulation from stabilized drainage areas is not expected to exceed an average of 4 inches per year in the first cell. If sediment accumulation is greater than this amount, it will be assumed to be from construction unless it can be shown otherwise.

Maintenance Considerations

1. Accumulated sediment and stagnant conditions may cause noxious gases to form and accumulate in the vault. Vault maintenance procedures must meet OSHA confined space entry requirements, which includes clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser(s), just under the access lid.
2. Facilities should be inspected annually. Floating debris and accumulated petroleum products should be removed as needed, but at least annually. The floating oil should be removed from wetvaults used as oil/water separators when oil accumulation exceeds one inch.
3. Sediment should be removed when the 1-foot (average) sediment zone is full plus no more than 6 inches. Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.
4. Water drained or pumped from the vault prior to removing accumulated sediments may be discharged to storm drains if it is not excessively turbid (i.e., if water appears translucent when held to light), if all floatable debris and visual petroleum sheen are removed, and if it is not a **prohibited discharge** as defined in Section 22.802.012 of the City of Seattle *Stormwater, Grading and Drainage Control Code*. Excessively turbid water (i.e., water appears opaque when held to light) should be discharged only after the settleable solids have been removed.

FIGURE 22. TYPICAL WETVAULT DETAILS (EXAMPLE 1)

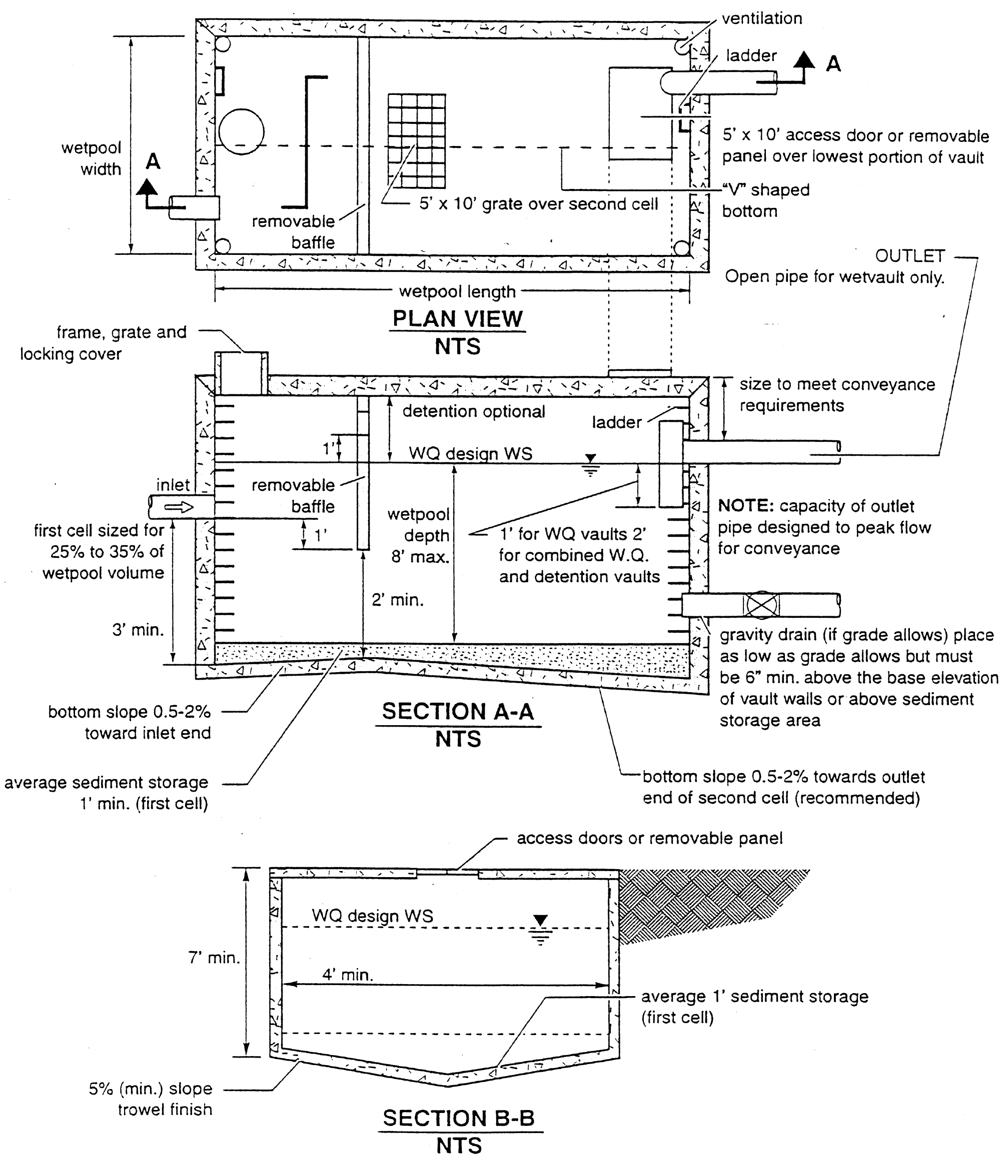
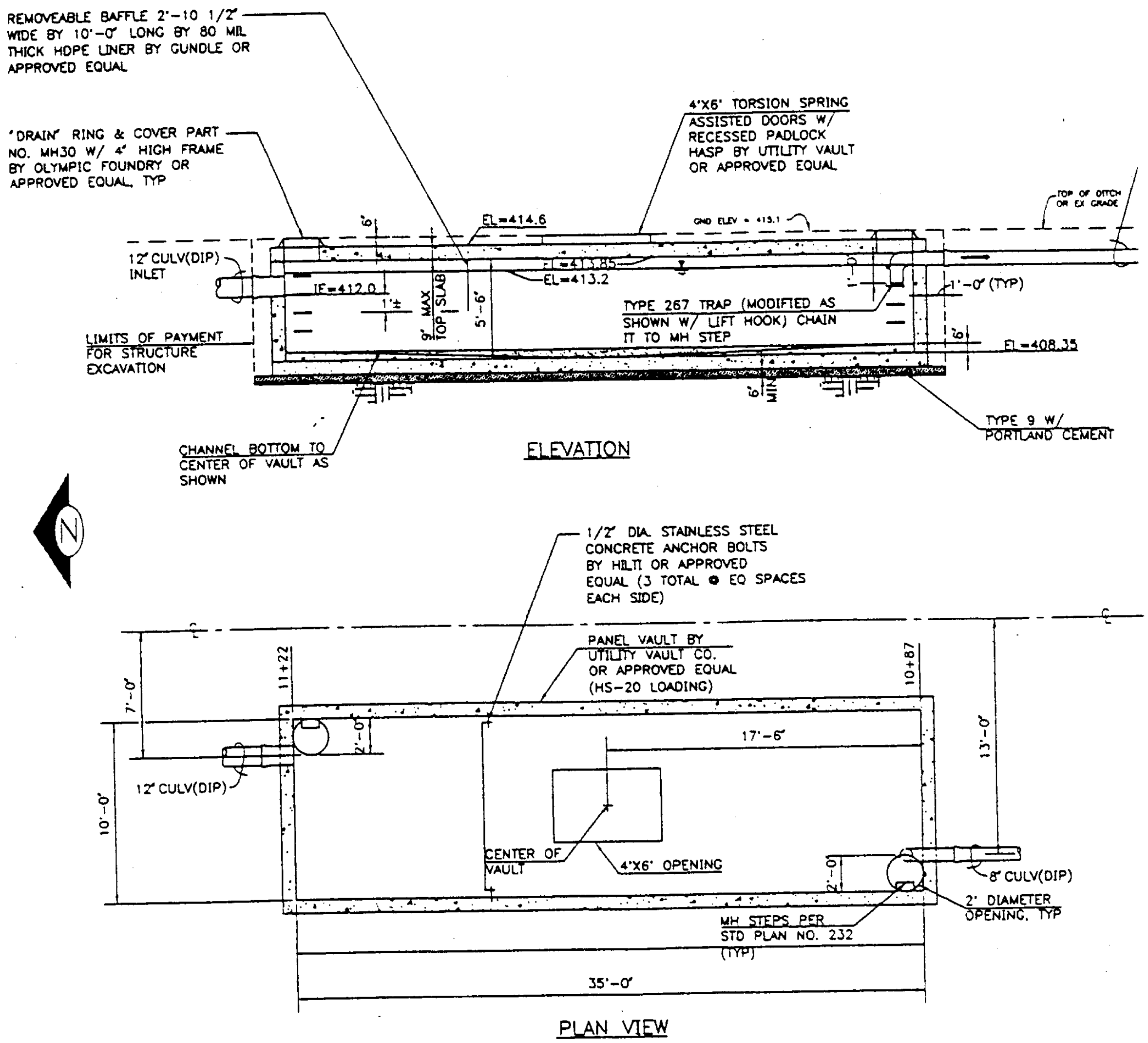


FIGURE 22. TYPICAL WETVAULT DETAILS (CONTINUED)
EXAMPLE 2



4.3 STORMWATER WETLANDS

In land development situations, wetlands are usually constructed for two main reasons: to replace or mitigate impacts when natural wetlands are filled or impacted by development (mitigation wetlands), and to treat stormwater runoff (stormwater treatment wetlands). *Stormwater wetlands* are shallow man-made ponds that are designed to treat stormwater through the biological processes associated with emergent aquatic plants (see the stormwater wetland details in Figure 23 (p. 102), and Figure 24 (p. 103).

Wetlands created to mitigate disturbance impacts, such as filling, may not also be used as stormwater treatment facilities. This is because of the different, incompatible functions of the two kinds of wetlands. **Mitigation wetlands** are intended to function as full replacement habitat for fish and wildlife, providing the same functions and harboring the same species diversity and biotic richness as the wetlands they replace. **Stormwater treatment wetlands** are used to capture and transform pollutants, just as wetponds are, and over time the sediment will concentrate pollutants. This is not a healthy environment for aquatic life. Stormwater treatment wetlands are used to capture pollutants in a managed environment **so that they will not reach natural wetlands** and other ecologically important habitats. In addition, vegetation must be harvested and sediment dredged in stormwater treatment wetlands, further interfering with use for wildlife habitat.

In general, stormwater wetlands perform well to remove sediment, metals, and pollutants which bind to humic or organic acids. Phosphorus removal in stormwater wetlands is highly variable.[27]

Applications and Limitations

This stormwater wetland design occupies about the same surface area as wetponds, but has the potential to be better integrated aesthetically into a site because of the abundance of emergent aquatic vegetation. The most critical factor for a successful design is the provision of an **adequate supply of water** for most of the year. Careful planning is needed to be sure sufficient water will be retained to sustain good wetland plant growth. Since water depths are shallower than in wetponds, water loss by evaporation is an important concern. Stormwater wetlands are a good water quality facility choice in areas with **high winter groundwater levels**.

4.3.1 Methods of Analysis

When used for stormwater treatment, stormwater wetlands employ some of the same design features as wetponds. However, instead of gravity settling being the dominant treatment process, pollutant removal mediated by aquatic vegetation and the microbiological community associated with that vegetation becomes the dominant treatment process. Thus when designing wetlands, water volume is not the dominant design criteria. Rather, factors which affect plant vigor and biomass are the primary concerns.

Steps 1 through 5: Determine the volume of a basic wetpond. Follow Steps 1 through 5 for wetponds (see page 77). The volume of a basic wetpond is used as a template for sizing the stormwater wetland.

Step 6: Calculate the surface area of the stormwater wetland. The surface area of the wetland shall be the same as the top area of a wetpond sized for the same site conditions. Calculate the surface area of the stormwater wetland by using the volume from Step 5 and dividing by the average water depth (use 3 feet).

[27] Richardson, C. 1987. "Mechanisms controlling phosphorus retention capacity in freshwater wetlands," *Science*, 228: 1424.

Step 7: Determine the surface area of the first cell of the stormwater wetland. Use the volume determined from Criterion 2 under "Wetland Geometry" (p. 99), and the actual depth of cell 1.

Step 8: Determine the surface area of the wetland cell. Subtract the surface area of the first cell (Step 7) from the total surface area (Step 6).

Step 9: Determine water depth distribution in the second cell. Decide if the top of the dividing berm will be at the surface or submerged (designer's choice). Adjust the distribution of water depths in the second cell according to Criterion 8 under "Wetland Geometry" below. *Note: This will result in a facility that holds less volume than that determined in Step 5 above. This is acceptable.*

Intent: The surface area of the stormwater wetland is set to be roughly equivalent to that of a wetpond designed for the same site so as not to discourage use of this option.

Step 10: Choose plants. See Table 12 (p. 87) for a list of plants recommended for wetpond water depth zones, or consult a wetland scientist.

4.3.2 Design criteria

Typical details for a **stormwater wetland** are shown in Figure 23 (p. 102) and Figure 24 (p. 103).

Wetland Geometry

1. Stormwater wetlands shall consist of two cells, a presettling cell and a wetland cell.
2. The **presettling cell** shall contain a volume equal to the volume of runoff from the mean annual storm (V_r). This is approximately 33% of the wetpool volume calculated in Step 5 of "Methods of Analysis," Section 4.3.1.
3. The **depth of the presettling cell** shall be between 4 feet (minimum) and 8 feet (maximum).
4. One foot of **sediment storage** shall be provided in the presettling cell.
5. The **wetland cell** shall have an average **water depth** of about 1.5 feet (plus or minus 3 inches).
6. The **"berm"** separating the two cells shall be shaped such that its downstream side gradually slopes to form the second shallow wetland cell (see the section view in Figure 23 (p. 102). Alternatively, the second cell may be graded naturalistically from the top of the dividing berm (see Criterion 8 below).
7. The **top of berm** shall be either at the water quality design water surface or submerged 1 foot below the water quality design water surface, as with wetponds. Correspondingly, the **side slopes** of the berm must meet the following criteria:
    a) If the top of berm is at the water quality design water surface, the berm side slopes shall be no steeper than 3H:1V.
    b) If the top of berm is submerged 1 foot, the upstream side slope may be up to 2H:1V.[28]
8. Two options (A and B) are provided for **grading the bottom of the wetland cell**. Option A is a shallow, evenly graded slope from the upstream to the downstream edge of the wetland cell (see Figure 23, p. 102). Option B is a "naturalistic" alternative, with the

[28] If the berm is at the water surface, then for safety reasons, its slope must be no greater than 3:1, just as the pond banks must be 3:1 if the pond is not fenced. A steeper slope (2:1 rather than 3:1) is allowed if the berm is submerged in 1 foot of water. If submerged, the berm it is not considered accessible, and the steeper slope is allowed.

specified range of depths intermixed throughout the second cell (see Figure 24 (p. 103)). A **distribution of depths** shall be provided in the wetland cell depending on whether the dividing berm is at the water surface or submerged (see Table 13 below). The maximum depth is 2.5 feet in either configuration.

TABLE 13. DISTRIBUTION OF DEPTHS IN WETLAND CELL			
DIVIDING BERM AT WATER QUALITY DESIGN WATER SURFACE		**DIVIDING BERM SUBMERGED 1 FOOT**	
Depth Range (feet)	**Percent**	**Depth Range (feet)**	**Percent**
0.1 to 1	25	1 to 1.5	40
1 to 2	55	1.5 to 2	40
2 to 2.5	20	2 to 2.5	20

Lining Requirements

1. **In infiltrative soils**, both cells of the stormwater wetland shall be lined. To determine whether a low-permeability liner or a treatment liner is required, determine whether the following conditions will be met. If soil permeability will allow sufficient water retention, lining may be waived.

   - The second cell must retain water for at least 10 months of the year.
   - The first cell must retained at least three feet of water year-round.

   Intent: Many wetland plants can adapt to periods of summer drought, so a limited drought period is allowed in the second cell. This may allow a treatment liner rather than a low permeability liner to be used for the second cell. The first cell must retain water year-round in order for the presettling function to be effective.

2. If a **low permeability liner** is used, a minimum of 18 inches of native soil amended with good topsoil or compost (one part compost mixed with 3 parts native soil) must be placed over the liner. For **geomembrane liners**, a soil depth of 3 feet is recommended to prevent damage to the liner during planting. Hydric soils are not required.

3. The criteria for liners given in Section 2.4 (p. 17) must be observed.

Inlet and Outlet

Same as for wetponds (see page 78).

Access and Setbacks

1. Location of the stormwater wetland relative to site constraints (e.g., buildings, property lines, etc.) shall be the same as for wetponds (see Page 81).

2. Access and maintenance **roads** shall be provided and designed according to the requirements for wetponds (see Page 81). Access and maintenance roads shall extend to both the wetland inlet and outlet structures. An access ramp (7H minimum:1V) shall be provided to the bottom of the first cell unless all portions of the cell can be reached and sediment loaded from the top of the wetland side slopes.

3. If the dividing berm is also used for access, it must be built to sustain loads of up to 80,000 pounds.

Signage

Signage shall be provided according to the requirements for wetponds (see Page 82).

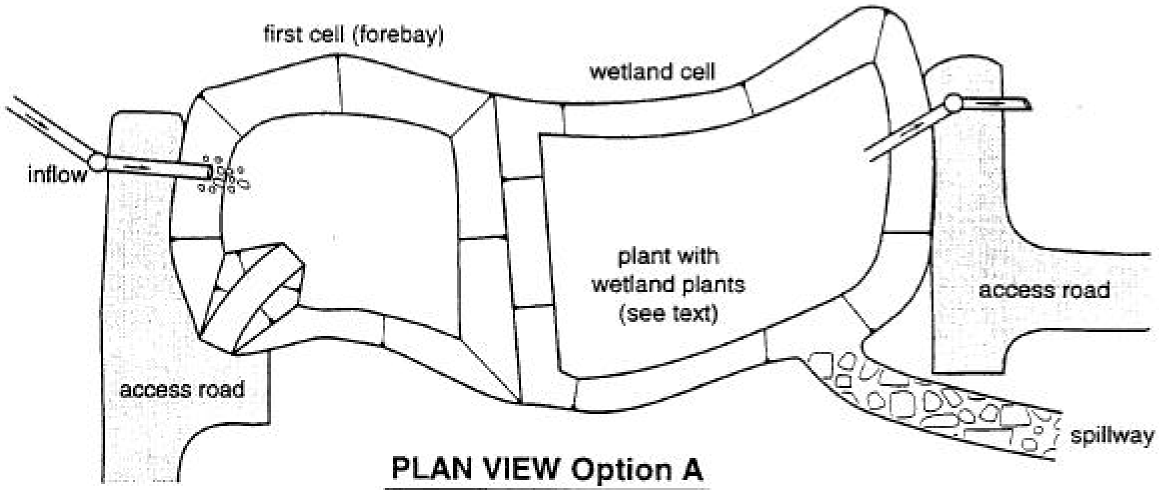
Planting Requirements

The wetland cell shall be planted with emergent wetland plants following the recommendations given in Table 12 (p. 87) or the recommendations of a wetland specialist. *Note: Cattails (Typha latifolia) are not recommended. They tend to escape to natural wetlands and crowd out other species. In addition, the shoots die back each fall and will result in oxygen depletion in the wetpool unless they are removed.*

Construction and Maintenance Considerations

Construction and maintenance considerations are the same as for basic wetponds. Construction of the naturalistic alternative (Option B) can be easily done by first excavating the entire area to the 1.5-foot average depth. Then soil subsequently excavated to form deeper areas can be deposited to raise other areas until the distribution of depths indicated in the design is achieved.

FIGURE 23. STORMWATER WETLAND — OPTION A



PLAN VIEW Option A
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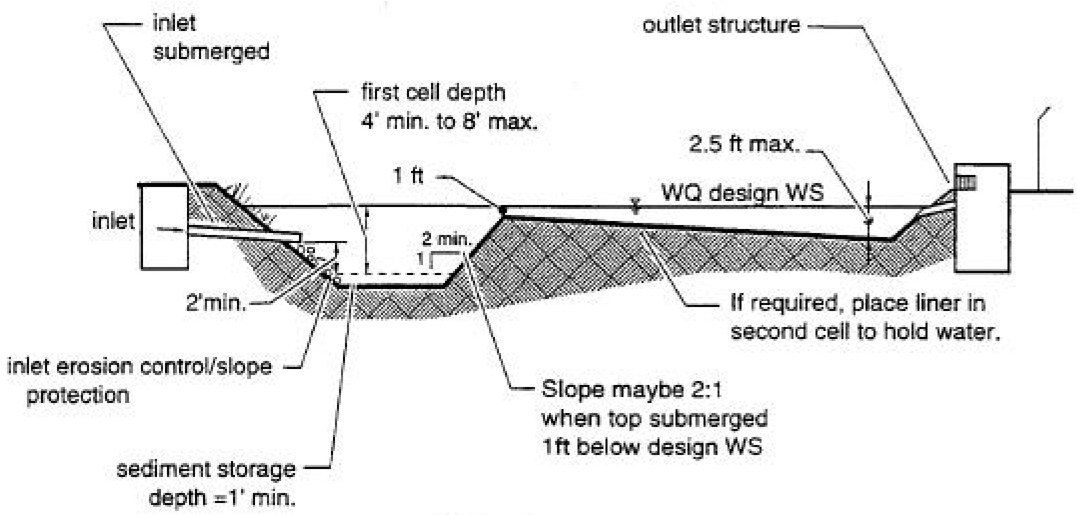

SECTION VIEW Option A
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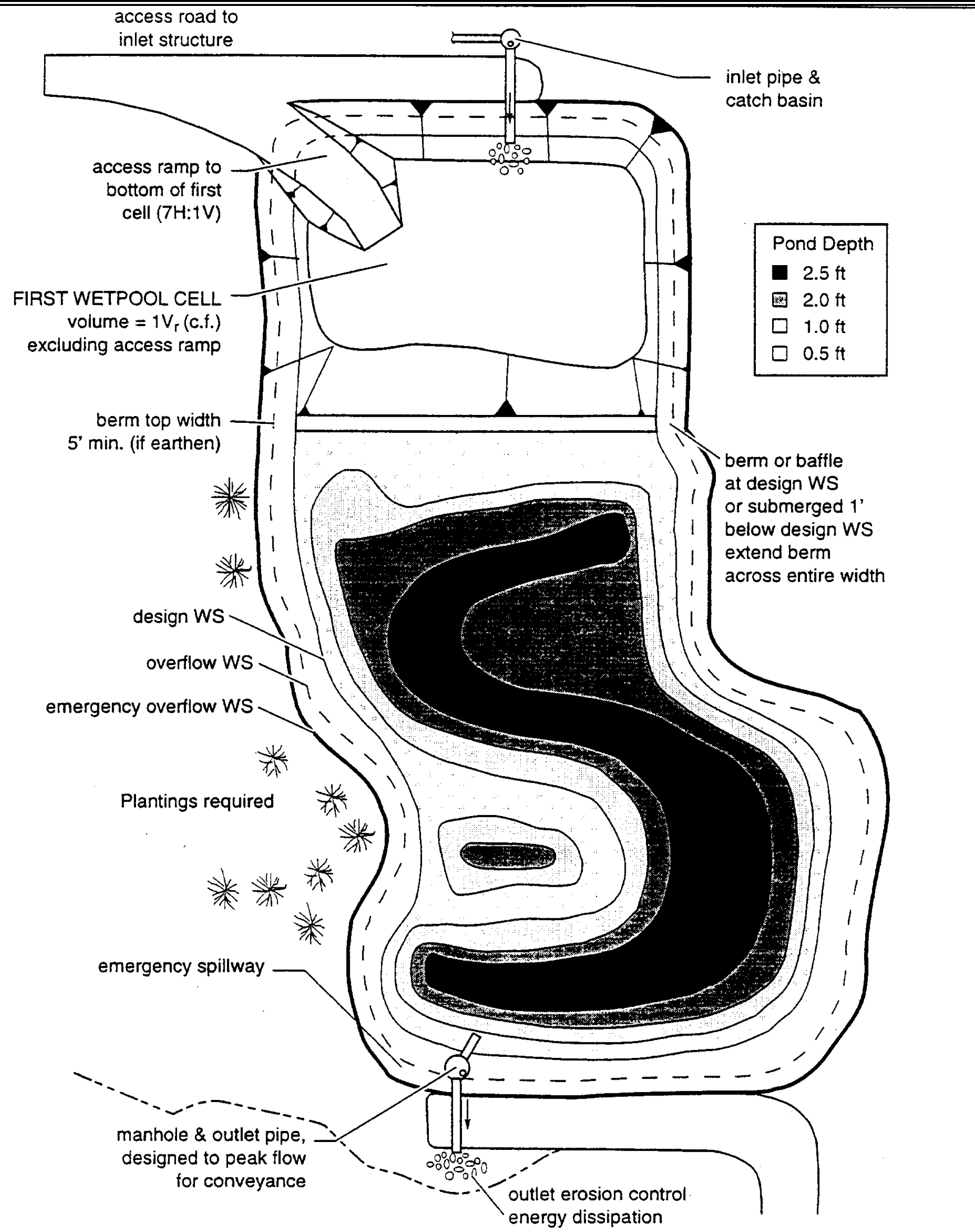
FIGURE 24. STORMWATER WETLAND — OPTION B



PLAN VIEW Option B

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4.4 COMBINED DETENTION AND WETPOOL FACILITIES

Combined detention and water quality wetpool facilities have the appearance of a detention facility but contain a permanent pool of water as well. The following design procedures, requirements, and recommendations cover differences in the design of the stand-alone stormwater treatment facility when combined with detention storage. The following combined facilities are addressed:

- Detention/wetpond
- Detention/wetvault
- Detention/stormwater wetland.

Applications and Limitations

Combined detention and water quality facilities are very efficient for sites that also have detention requirements. The water quality facility may often be placed beneath the detention facility without increasing the facility surface area. However, the **fluctuating water surface** of the live storage will create unique challenges for plant growth and for aesthetics alike.

The basis for pollutant removal in combined facilities is the same as in the stand-alone stormwater treatment facilities. However, in the combined facility, the detention function creates fluctuating water levels and added turbulence. For simplicity, the positive effect of the extra live storage volume and the negative effect of increased turbulence are assumed to balance, and are thus ignored when sizing the wetpool volume.[29] For the combined detention/stormwater wetland, criteria that limit the extent of water level fluctuation are specified to better ensure survival of the wetland plants.

Unlike the wetpool volume, the **live storage component** of the facility should be provided above the seasonal high water table.

4.4.1 Methods of Analysis

❑ COMBINED DETENTION AND WETPOND

Follow the procedure specified in Section 4.1.1 (p. 69) to determine the wetpool volume for a combined facility. The detention portion of the pond must be calculated using methods equivalent to those outlined in the Flow Control Technical Requirements Manual, and must meet the flow control requirements specified in the Stormwater, Grading and Drainage Control Code.

❑ COMBINED DETENTION AND WETVAULT

Follow the procedure specified in Section 4.2.1 (p. 90) to determine the wetvault volume for a combined facility. The detention portion of the vault must be calculated using methods equivalent to those outlined in the Flow Control Technical Requirements Manual, and must meet the flow control requirements specified in the Stormwater, Grading and Drainage Control Code.

❑ COMBINED DETENTION AND STORMWATER WETLAND

Follow the procedure specified in Section 4.3.1 (p.98) to determine the stormwater wetland size. The detention portion of the wetland must be calculated using methods equivalent to those

[29] Many of the ponds studied in the Nationwide Urban Runoff Program were combined ponds.

outlined in the Flow Control Technical Requirements Manual, and must meet the flow control requirements specified in the Stormwater, Grading and Drainage Control Code.

4.4.2 Design Criteria

❑ COMBINED DETENTION AND WETPOND

Typical design details and concepts for a combined detention and wetpond are shown in Figure 25 (p. 108). The **detention portion** of the facility shall meet the meet the flow control requirements of the Stormwater, Grading and Drainage Control Code.

General

1. Ponds **must be designed as flow-through systems**. Developed flows must enter through a conveyance system separate from the control structure and outflow conveyance system. Maximizing distance between the inlet and outlet is encouraged to promote sedimentation.
2. **Pond bottoms shall be level** and be located a minimum of 6 inches below the inlet and outlet to provide sediment storage.
1. Outflow **control structures** shall be designed to meet the flow control requirements for detention systems as contained in the Stormwater, Grading and Drainage Control Code.
3. as specified in the City of Seattle Directors' Rule for Flow Control.
4. A **geotechnical analysis** and report may be required on slopes over 15% or if located within 200 feet of the top of a steep slope or landslide hazard area.

Side Slopes

1. **Interior side slopes** up to the emergency overflow water surface shall be no steeper than 3H:1V unless a fence is provided.
2. **Exterior side slopes** shall be no steeper than 2H:1V unless analyzed for stability by a geotechnical engineer.
3. **Pond walls** may be vertical retaining walls, provided:
   a) They are constructed of reinforced concrete;
   b) A fence is provided along the top of the wall;
   c) At least 25% of the pond perimeter will be a vegetated soil slope not steeper than 3H:1V; and
   d) The design is stamped by a licensed structural civil engineer.
4. For **privately owned and maintained facilities**, the entire pond perimeter may be retaining wall, meeting the City of Seattle building code requirements.

Detention and Wetpool Geometry

1. The wetpool and sediment storage volumes shall not be included in the required detention volume.
2. The **"Wetpool Geometry"** criteria for wetponds (see page 77) shall apply with the following **modifications/clarifications:**

a) **Criterion 1:** The **permanent pool** may be made shallower to take up most of the pond bottom, or deeper and positioned to take up only a limited portion of the bottom. Note, however, that having the first wetpool cell at the inlet allows for more efficient sediment management than if the cell is moved away from the inlet. Wetpond criteria governing water depth must, however, still be met. See Figure 26 (p. 110) for two possibilities for wetpool cell placement.

Intent: This flexibility in positioning cells is provided to allow for multiple use options, such as volleyball courts in live storage areas in the drier months.

b) **Criterion 3:** The minimum **sediment storage depth** in the first cell is 1 foot. The 6 inches of sediment storage required for detention ponds does not need to be added to this, but 6 inches of sediment storage must be added to the second cell to comply with the detention sediment storage requirement.

Berms, Baffles, and Slopes

Same as for wetponds (see page 77).

Inlet and Outlet

The "Inlet and Outlet" criteria for **wetponds** (see page 78) shall apply with the following **modifications:**

2. **Criterion 2:** A **sump** must be provided in the outlet structure of combined ponds.
3. The detention flow restrictor and its outlet pipe shall be designed to meet the flow control requirements for detention systems as contained in the Stormwater, Grading and Drainage Control Code.

Access and Setbacks

Same as for wetponds (see page 80).

Signage

Same as for wetponds (see page 82).

Planting Requirements

Same as for wetponds (see page 83).

❑ COMBINED DETENTION AND WETVAULT

The design criteria for detention vaults and wetvaults must **both** be met, except for the following **modifications or clarifications:**

1. The minimum **sediment storage depth** in the first cell shall average 1 foot. The 6 inches of sediment storage required for detention vaults does not need to be added to this, but 6 inches of sediment storage must be added to the second cell to comply with detention vault sediment storage requirements.
2. The **oil retaining baffle** shall extend a minimum of 2 feet below the water quality design water surface.

Intent: The greater depth of the baffle in relation to the water quality design water surface compensates for the greater water level fluctuations experienced in the combined vault. The greater depth is deemed prudent to better ensure that separated oils remain within the vault, even during storm events.

❑ COMBINED DETENTION AND STORMWATER WETLAND

The design criteria for detention ponds and stormwater wetlands must both be met, except for the following **modifications or clarifications:**

1. The **"Wetland Geometry"** criteria for stormwater wetlands (see page 99) are modified as follows:

   Criterion 4: The minimum **sediment storage depth** in the first cell is 1 foot. The 6 inches of sediment storage required for detention ponds does not need to be added to this, nor does the 6 inches of sediment storage in the second cell of detention ponds need to be added.

   Intent: Since emergent plants are limited to shallower water depths, the deeper water created before sediments accumulate is considered detrimental to robust emergent growth. Therefore, sediment storage is confined to the first cell which functions as a presettling cell.

2. The "**Inlet and Outlet**" criteria for **wetponds** (see page 78) shall apply with the following **modifications:**

   a) **Criterion 2:** A **sump** must be provided in the outlet structure of combined facilities.

   b) The detention **flow restrictor** and its outlet pipe shall be designed to meet the flow control requirements for detention systems as contained in the Stormwater, Grading and Drainage Control Code.

3. The **"Planting Requirements"** for stormwater wetlands (see page 101) are **modified** to use the following plants which are better adapted to water level fluctuations:

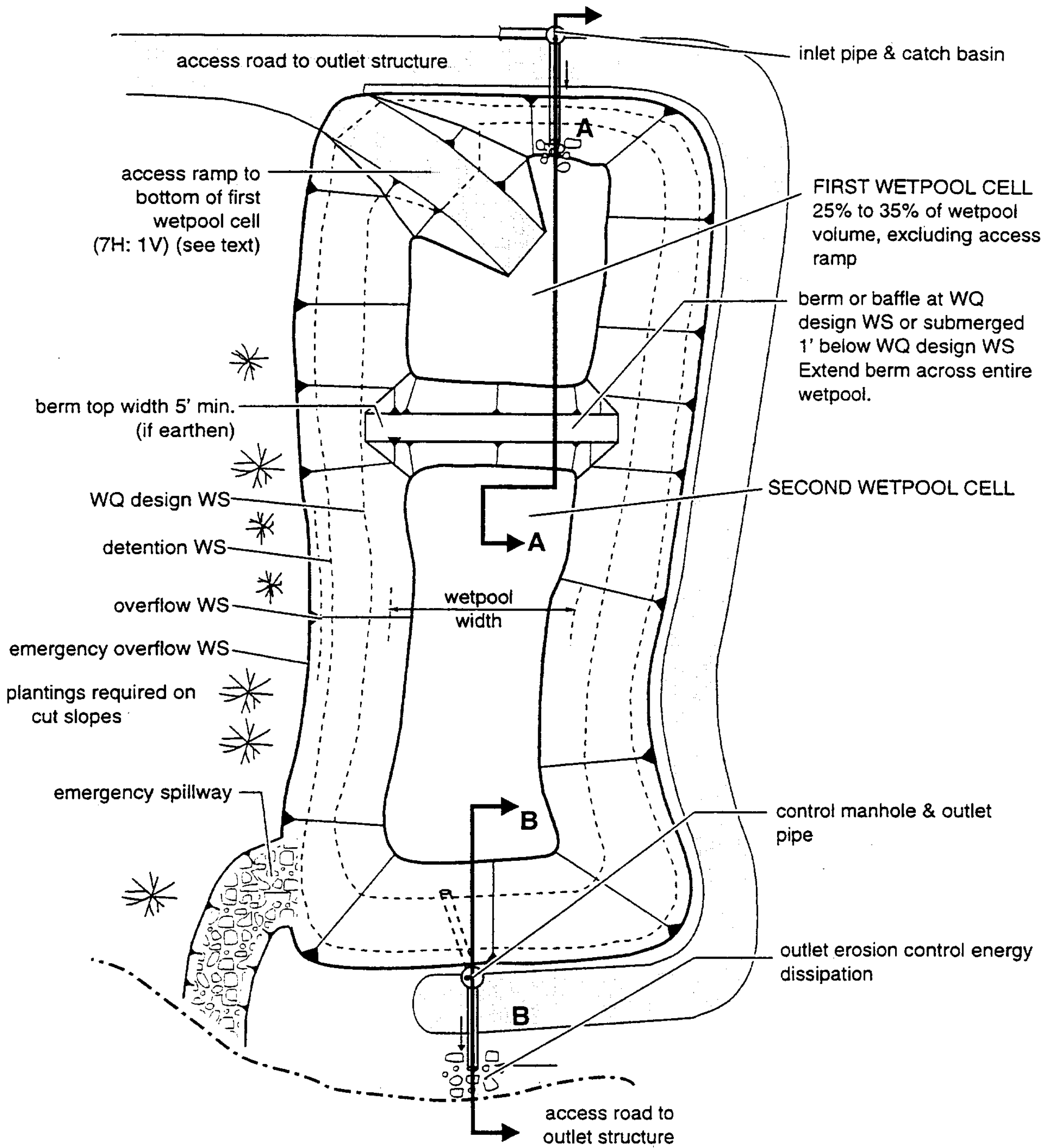
   - *Scirpus acutus* (hardstem bulrush) 2 - 6' depth
   - *Scirpus microcarpus* (small-fruited bulrush) 1 - 2.5' depth
   - *Sparganium emersum* (burreed) 1 - 2' depth
   - *Sparganium eurycarpum* (burreed) 1 - 2' depth
   - *Veronica* sp. (marsh speedwell) 0 - 1' depth

   In addition, the shrub *Spirea douglasii* (Douglas spirea) may be used in combined facilities.

   Water Level Fluctuation Restrictions: The difference between the water quality design water surface and the maximum water surface associated with the 2-year runoff shall not be greater than 3 feet. If this restriction cannot be met, the size of the stormwater wetland must be increased. The **additional area** may be placed in the first cell, second cell, or both. If placed in the second cell, the additional area need not be planted with wetland vegetation or counted in calculating the average depth.

   Intent: This criterion is designed to dampen the most extreme water level fluctuations expected in combined facilities to better ensure that fluctuation-tolerant wetland plants will be able to survive in the facility. It is **not intended** to protect native wetland plant communities and is **not to be applied to natural wetlands**.

FIGURE 25. COMBINED DETENTION AND WETPOND



PLAN VIEW
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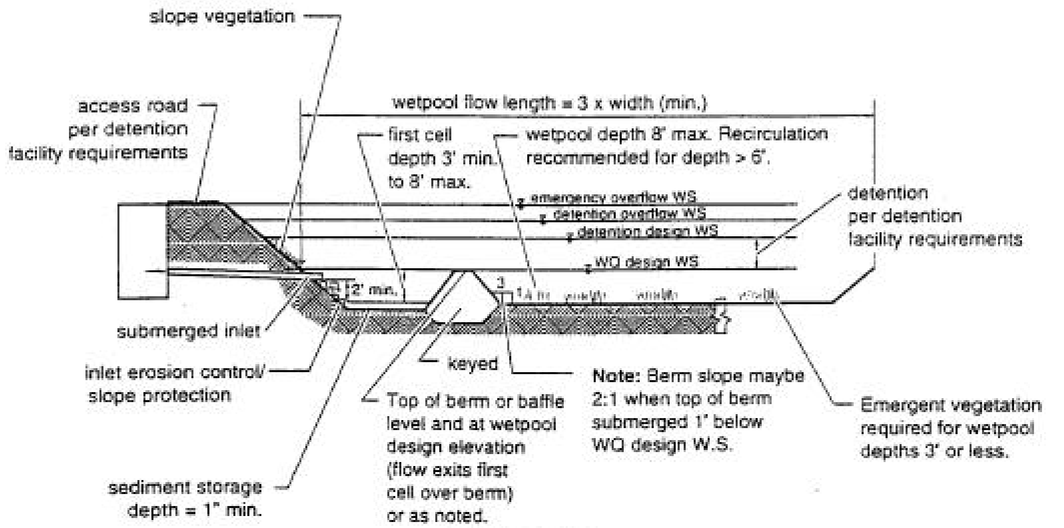
FIGURE 25. COMBINED DETENTION AND WETPOND (*CONTINUED*)



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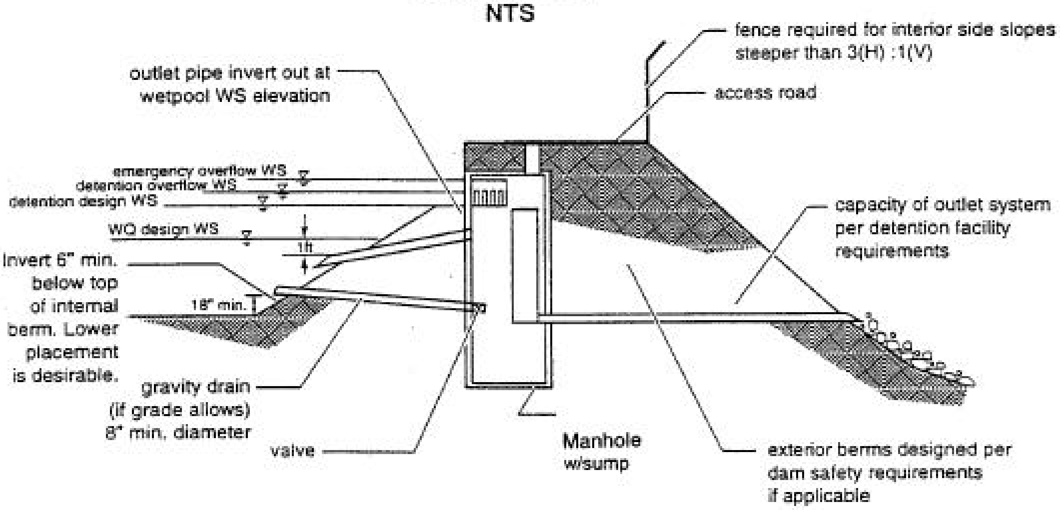

SECTION B-B
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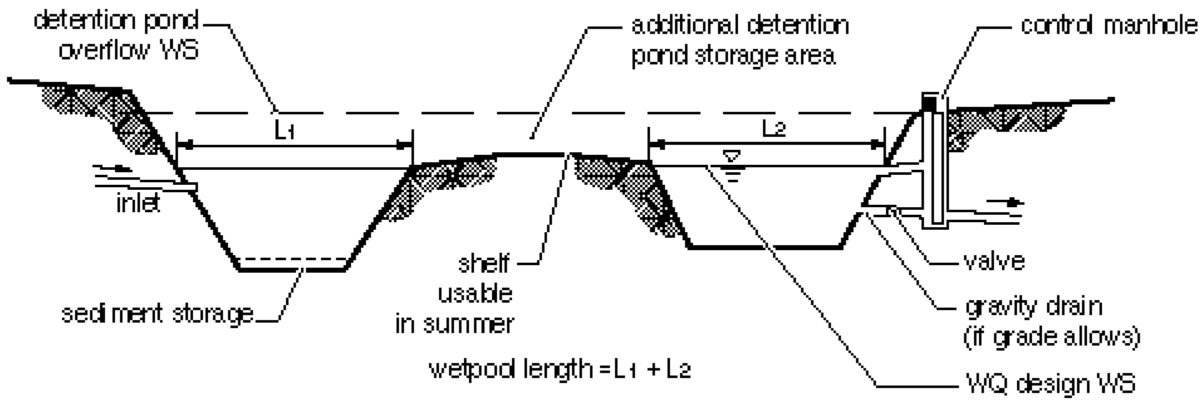
FIGURE 26. ALTERNATIVE CONFIGURATIONS OF DETENTION AND WETPOOL AREAS



SECTION VIEW
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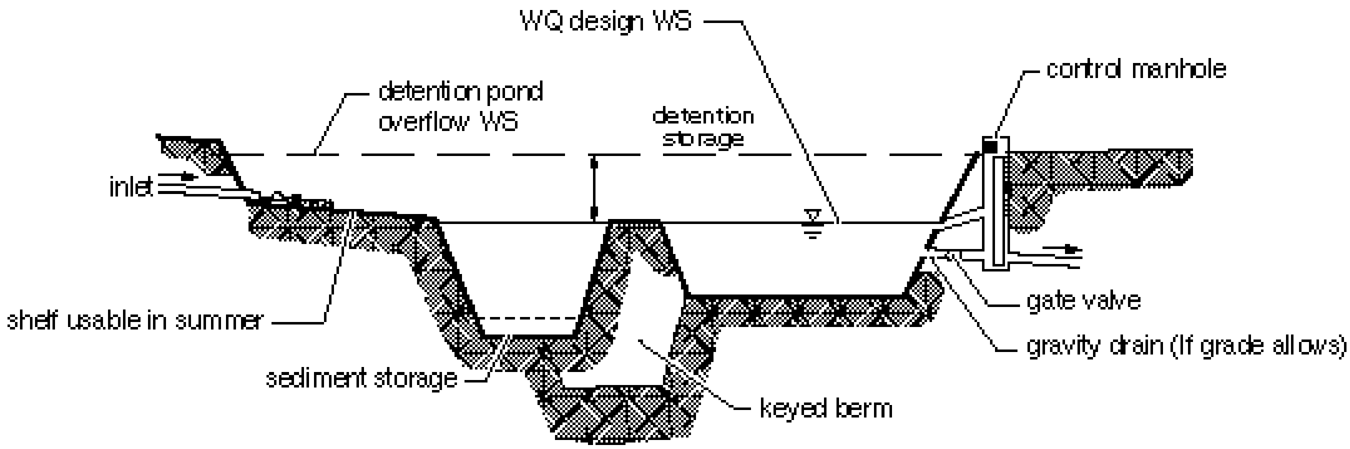

SECTION VIEW
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Note: These examples show how the combined detention/wetpool can be configured to allow for "shelves" for joint use opportunities in dry weather. Other options may also be acceptable.

5 MEDIA FILTRATION FACILITY DESIGNS

This section presents the methods, criteria, and details for analysis and design of sand filters and generic information for leaf compost filters. Specifically, the following specific facility designs are included in this section:

- Sand Filters, Section 5.2
- Sand Filter Vaults, Section 5.3
- Linear Sand Filters, Section 5.4
- Stormfilter™, Section 5.5

The information presented for each filtration facility is organized into the following categories:

1. **Methods of Analysis:** Contains a step-by-step procedure for designing and sizing each facility. Information used in the procedure is based on available literature, but clarified or modified where deficiencies were identified.[30]
2. **Design Criteria:** Contains the details, specifications, and material requirements for each facility.

5.1 MEDIA FILTRATION FACILITIES

Presettling Requirement

Filtration facilities are particularly susceptible to clogging. Presettling must therefore be provided before stormwater enters a filtration facility. This requirement may be met by **any of the following:**

1. A basic stormwater treatment facility (see Section 1.2.2 for facility options).
2. A presettling pond or vault, which can be integrated as the first cell of the filtration facility, with a treatment volume equal to 0.75 times the runoff from the mean annual storm (V_r = 0.75). See page 69 for information on computing V_r. See design requirements below. *Note: For the linear sand filter, use the sediment cell sizing given in the design instead of the above sizing.*
3. A detention facility.

Other Pretreatment Requirements

1. Sand filters not preceded by a facility that captures floatables, such as a spill control tee, must provide pretreatment to remove **floatable trash and debris** before flows reach the sand bed. This requirement can be met by providing a catch basin with a capped riser on the inlet to the sand filter (see Figure 29, p. 129).
2. For high-use sites, sand filters must be preceded by a spill control facility, such as a catch basin or vault with baffle plates.[31]

[30] Such modifications were often based on computer modeling using the King County Runoff Time Series (KCRTS) model. Less frequently, they were based on bench-scale studies.

[31] The King County *Surface Water Design Manual* (1998) requires that for high use sites, sand filters be preceded by an oil/water separator.

Design Criteria For Presettling Cells

1. If water in the presettling cell or upstream stormwater treatment facility will be in direct contact with the soil, it must be **lined** per the liner requirements in Section 2.4 (see page 17).

   Intent: to prevent groundwater contamination from untreated stormwater runoff in areas of excessively drained soils.

2. The presettling cell shall conform to the following:

   a) The **length-to-width ratio** should be 3:1. Berms or baffles may be used to lengthen the flow path.

   b) The **minimum depth** is recommended to be 3 feet; the **maximum depth** shall be 6 feet.

3. Inlets and outlets shall be designed to minimize velocity and reduce turbulence.

5.2 SAND FILTERS[32]

A open *sand filter* (see the sand filter detail in Figure 28 p. 127) operates much like an infiltration pond. However, instead of infiltrating into native soils, filters stormwater through a constructed sand bed with an underdrain system. Runoff enters the pond and spreads over the surface of the filter. As flows increase, water backs up in the pond where it is held until it can percolate through the sand. The treatment pathway is vertical (downward through the sand) rather than horizontal as it is in biofiltration swales and filter strips. Flows in excess of the water quality design flow simply spill out over the top of the pond. Water that percolates through the sand is collected in an underdrain system of drain rock and pipes which directs the treated runoff to the downstream drainage system.

A sand filter removes pollutants by filtration. As stormwater passes through the sand, pollutants are trapped in the small spaces between sand grains or adhere to the sand surface. Over time, soil bacteria will also grow in the sand bed, and some biological treatment may occur. To get better performance from a sand filter, the volume of water spilled over the top should be reduced. Increasing the sand thickness will not dependably improve performance.

Applications and Limitations

A sand filter can be used in most residential, commercial, and industrial developments where site topography and drainage provide adequate hydraulic head to operate the filter. **An elevation difference of about 4 feet between the inlet and outlet of the filter is usually needed** to install a sand filter.

Sand filters could be easily integrated into landscape plans as areas for summer sports, such as volleyball. Landscape uses may be somewhat constrained because the vegetation capable of surviving in sand is limited. Trees and shrubs which generate a large leaf fall should be avoided in the immediate vicinity of the filter because leaves and other debris can clog the surface of the filter.

Sand filters are designed to prevent water from backing up into the sand layer (the underdrain system must drain freely). Therefore, a sand filter is more **difficult to install in areas with high water tables** where groundwater could potentially flood the underdrain system. Water standing in the underdrain system will also keep the sand saturated. Under these conditions, oxygen can be depleted, releasing pollutants such as metals and phosphorus that are more mobile under anoxic conditions.

Because the surface of the sand filter will clog from sediment and other debris, this facility **should not be used in areas where heavy sediment loads are expected**. A sand filter should not be used during construction to control sediments unless the sand bed is replaced periodically during construction and after the site is stabilized.

5.2.1 Methods of Analysis

A sand filter is designed with two parts: (1) a **temporary storage reservoir** to store runoff, and (2) a **sand filter bed** through which the stored runoff must percolate. Usually the storage reservoir is simply placed directly above the filter, and the floor of the reservoir pond is the top of

[32] Note: The King County *Surface Water Design Manual* (1998) includes specifications for both *basic* and *large* sand filters. The requirements in the Seattle *Stormwater, Grading and Drainage Control Code* can be met by a basic sand filter described here.

the sand bed. For this case, the storage volume also determines the hydraulic head over the filter surface, which increases the rate of flow through the sand.

The **simple method** described below uses standard values to define filter hydraulic characteristics for determining the sand surface area. This method is useful for planning purposes, for a first approximation to begin iterations in the detailed method, or when use of the detailed computer model is not desired or not available. The simple sizing method **very often results in a larger filter** than the detailed method.

More robust calculation methods, using the King County Runoff Time Series (KCRTS) computer model or another detailed routing method, may be used. Use of the KCRTS design method **very often results in smaller filter sizes** than the simple method, **especially if the facility is downstream of a detention facility**. Additional information on the KCRTS detailed routing method can be found in the 1998 King County Surface Water Design Manual.

Background

There are several variables used in sand filter design which are similar and often confused, even by well-trained individuals. Use of these variables is explained below.

The sand filter design is based on Darcy's law:

$$Q = KiA \tag{5-1}$$

where
Q = water quality design flow (cfs)
K = hydraulic conductivity (fps)
A = surface area perpendicular to the direction of flow (sf)
i = hydraulic gradient (ft/ft) for a constant head and constant media depth, computed as follows:

$$i = \frac{h + l}{l} \tag{5-2}$$

where
h = average depth of water above filter (ft), defined for this design as $d/2$
d = maximum storage depth above filter (ft)
l = thickness of sand media (ft)

Although it is not seen directly, Darcy's law underlies both the simple and the routing design methods. ***V***, or more correctly, ***1/V***, is the direct input in the sand filter design. The relationship between V and K is revealed by equating Darcy's law and the equation of continuity, $Q = VA$. *Note: When water is flowing into the ground, V is commonly called the **filtration rate**. It is ordinarily measured in a percolation test.*

Specifically:

$$Q = KiA \quad \text{and} \quad Q = VA$$

so

$$VA = KiA \quad \text{or} \quad V = Ki \tag{5-3}$$

Note that $V \neq K$—that is, the filtration rate is not the same as the hydraulic conductivity, but they do have the same units (distance per time). *K* can be equated to *V* by dividing *V* by the hydraulic gradient *i*, which is defined above in Equation (5-2).

The hydraulic conductivity ***K* does not change with head** nor is it dependent on the thickness of the media, only on the characteristics of the media and the fluid. The hydraulic conductivity of 1 inch per hour (2.315×10^{-5} fps) used in this design is based on bench-scale tests of conditioned rather than clean sand. This design hydraulic conductivity represents the average sand bed condition as silt is captured and held in the filter bed.[33]

Unlike the hydraulic conductivity, the filtration rate ***V* changes with head and media thickness**, although the media thickness is constant in the sand filter design. Table 14 on page 116 shows values of *V* for different water depths *d* (remember, $d = 2h$).

The KCRTS program uses the inverse of the filtration rate, $1/V$, in units of minutes per inch; this is how Darcy's law is expressed in the design. The simple method is also based on $1/V$, but flows and areas are computed for the user in terms of acre equivalents. Thus both the simple and the KCRTS method are based on Darcy's law.

The simple sizing method is different from the KCRTS method because it does not route flows through the filter. It determines the size of the filter based on the simple assumption that inflow is immediately discharged through the filter as if there were no storage volume. An **adjustment factor**–the 0.7 in Equation (5-4)–is applied to compensate for the greater filter size resulting from this method. Even with this adjustment factor, however, the simple method generally produces larger filter sizes than the detailed routing method.

Simple Sizing Method

The simple method has been developed to design sand filters that meet the required treatment volume without performing detailed modeling. Steps for the simple sizing procedure are summarized below.

Step 1: Determine the rainfall region and regional scale factor. Regional scale factors are used to account for differences in rainfall between different rainfall gauging stations. For the Seattle area, use a scale factor of 1.0.

Step 2: Determine maximum depth of water above sand filter. Determine the maximum water storage depth above the surface of the filter. This depth is defined as the depth at which water begins to overflow the reservoir pond, and it depends on site topography and hydraulic constraints. The depth is chosen by the designer.

Step 3: Determine site characteristics. Determine the total number of impervious acres and the total number of grass acres draining to the sand filter. Determine whether the site is on till or outwash soils. Refer to Table 10 (Page 72) to determine which soil types are considered till and which are considered outwash.

Step 4: Calculate minimum required surface area for sand filter. Determine the sand filter area by multiplying the values in Table 15 by the site acreage from Step 4 using the following equation:

[33] King County has tested various sand mixes conditioned with simulated stormwater to establish realistic design standards. Tests were conducted under falling head conditions in columns containing 18 inches of sand underlain with a 2-inch layer of washed drain gravel containing a section of 2-inch perforated PVC pipe to simulate the underdrain system. Details are given in Koon, John, "Determination of infiltration rate and hydraulic conductivity for various sand filter media. " January 1996.

$$A_{sf} = 0.7C_s\,(T_iA_i + T_{tg}A_{tg} + T_{og}A_{og}) \qquad (5\text{-}4)$$

where A_{sf} = sand filter area (sf)
0.7 = adjustment factor to account for routing effect on size
C_s = regional scale factor (unitless) from Step 2 (=1.0 for Seattle)
$T_{i,tg,og}$ = tributary area per soil/cover type (acres)
$A_{i,tg,og}$ = filter area per soil/cover type (sf/acre) from Table 15

For depths between the values given in the table, areas can be interpolated. For depths outside the range presented in the table, the detailed routing method must be used.

Step 5. Size the underdrain system. The underdrain system is sized to convey the peak filtered flows to the outlet. The design criteria in "Underdrain Systems" (p. 120) can be used in lieu of analyzing conveyance capacity for feeder pipes. Strip drains must be analyzed for conveyance per manufacturer's specifications.

The collector pipe (i.e., the pipe collecting flows from the rest of the underdrain system) shall be sized to convey the 2-year, 15-minute peak flow with one foot of head above the invert of the upstream end of the collector pipe. Conveyance capacity can be checked using the "BW" computer program.

Intent: The underdrain must be able to remove standing water from beneath the sand. If standing water remains, the sand will remain saturated. This could cause oxygen depletion and reducing conditions in the sand, allowing some pollutants to become mobile and be released from the filter to downstream receiving waters.

TABLE 14. SAND FILTER DESIGN PARAMETERS

	Sand Filter Design Parameters					
Facility ponding depth *d* (ft)	1	2	3	4	5	6
Filtration rate *V* (in/hr)*	1.33	1.67	2.00	2.33	2.67	3.00
1/V (min/in)	45	36	30	26	22.5	20

* Note: The filtration rate is not used directly, but is provided for information. *V* equals the hydraulic conductivity, *K*, times the hydraulic gradient, *i*. The hydraulic conductivity used is *1* inch/hr. The hydraulic gradient = (h + l)/l, where $h = d/2$ and l = the sand depth (1.5 ft).

TABLE 15. SAND FILTER AREA INCREMENTS FOR VARIOUS SOIL AND COVER TYPES				
Region and Treatment Goal	Maximum Depth above filter (ft)	SOIL AND COVER TYPES[34] [filter area (sf) / tributary area (acre)]		
		A_i Impervious	A_{tg} Till Grass	A_{og} Outwash Grass
SeaTac (Basic size)	6	760	160	140
	3	1140	240	210
	1	1711	360	314
Note: Forested areas may be ignored. Vegetated areas other than grass may still be represented as grass for the simple sizing method, or the detailed routing method may be employed using actual cover types.				

Simple Method Sizing Example

For a site in the City of Seattle with 2 acres of impervious area and 2 acres of till grass draining to the sand filter, and 3 feet of head above the filter, the **required sand area** for a **basic size sand filter** would be found as follows:

Site Areas			Table 15 values for SeaTac, basic size	
	2 acres	x	1,140 sf/acre	= 2,280 sf
+	2 acres	x	240 sf/acre	= 480 sf
				= 2,760 sf

Because the site is located in Seattle, the "regional scale factor" is 1.0. Multiply the 2,760 square feet by the 0.7 adjustment factor.

2,760 sf x 1.0 x 0.7 = 1,930 sf

The required sand bed area is therefore **1,930 square feet.**

Note: Find the total facility area by adding 3H:1V side slopes for the 3 foot ponding depth plus extra vertical height to convey the 100-year flow. If the total pond depth is 3.5 feet, the sand filter will require a total land area of (44 ft + 10.5 ft) x (44 ft + 10.5 ft) = 2.970 square feet, plus access and setback requirements.

[34] The values in Table 15 were derived as follows. Flows were estimated using the KCRTS model for one acre of the cover types selected in the table. Darcy's law ($Q = Ki A$) was then used to determine sand filter area using this flow Q, the hydraulic gradient i for the various ponding depths given, and a hydraulic conductivity k of 2.3 X 10^{-5} fps (1 inch/hr). The hydraulic gradient i was calculated as $(h+l)/l$, where h = the average depth of water above the filter, taken to be the ponding depth $d/2$, and l = the thickness of the sand layer, which is 1.5 feet. The hydraulic conductivity represents a partially plugged sand condition found by bench-scale testing using successive trials with turbid water.

5.2.2 Design Criteria

General design concepts and a typical layout of a sand filter are shown in Figure 28 (p. 127) and Figure 29 (p. 129).

Sand Filter Geometry

1. **Any shape** sand bed may be used, including circular or free-form designs. *Note: The treatment process is governed by* ***vertical*** *flow, so short-circuiting is not a concern as it is in wetponds.*
2. **Sand depth** (*l*) shall be 18 inches (1.5 feet) minimum.
3. **Depth of storage** over the filter media (*d*) shall be 6 feet maximum.

Pretreatment, Flow Spreading, and Energy Dissipation

1. See general presettling and pretreatment requirements for filtration facilities in Section 5.1 (p. 111).
2. A **flow spreader** shall be installed at the inlet along one side of the filter to evenly distribute incoming runoff across the filter and prevent erosion of the filter surface. See Section 2.5 (p. 27) for details on flow spreaders.
   a) **If the sand filter is curved or an irregular shape**, a flow spreader shall be provided for a minimum of 20% of the filter perimeter.
   b) If the **length-to-width ratio** of the filter is 2:1 or greater, a flow spreader must be located on the longer side and for a **minimum length** of 20% of the facility perimeter.
   c) In other situations, use good engineering judgment in positioning the spreader.
3. **Erosion protection** shall be provided along the first foot of the sand bed adjacent to the flow spreader. Geotextile (meeting the specifications in **Error! Reference source not found.** (p. 120) weighted with sand bags at 15-foot intervals may be used. Quarry spalls may also be used.

Overflow and Bypass Structures

1. **On-line filters**[35] shall be equipped with **overflows** (primary, secondary, and emergency) in accordance with the design criteria for wetponds. *Note: The primary overflow may be incorporated into the emergency spillway in cases where the spillway discharges into a downstream detention facility, or where overflows can be safely controlled and redirected into the downstream conveyance system.*
2. For **off-line filters**, the outlet structure must be designed to pass the 2-year peak inflow rate.

   Intent: Overflow capacity is required for low-flow, high-volume storms which may exceed the storage capacity of the filter.
3. To the extent base flow conditions can be identified, **base flow** must be bypassed around the filter to keep the sand from remaining saturated for extended periods of time.

[35] Whether a stormwater treatment facility is designed as on-line (all flow going through the facility) or off-line (high flows bypassing the facility) is a choice made by the designer. Section 2.5 (p. 23) contains information on flow splitters for WQ facilities.

Filter Composition

A sand filter consists of three or four layers:

- Top layer (optional): grass seed or sod grown in sand
- Second layer: sand
- Third layer geotextile fabric
- Fourth layer: underdrain system.

Sand Specifications

The sand in a filter shall consist of a medium sand with few fines meeting the size gradation (by weight) given in Table 16. The contractor must obtain a grain size analysis from the supplier to certify that the No. 100 and No. 200 sieve requirements are met. *Note: Many sand mixes supplied locally meet this specification. However, standard backfill for sand drains (as specified in the Washington Standard Specifications 9-03.13) does not meet this specification and should not be used for sand filters.*

TABLE 16. SAND MEDIA SPECIFICATIONS

U.S. Sieve Size	Percent passing
U.S. No. 4	95 to 100 percent
U.S. No. 8	70 to 100 percent
U.S. No. 16	40 to 90 percent
U.S. No. 30	25 to 75 percent
U.S. No. 50	2 to 25 percent
U.S. No. 100	Less than 4 percent
U.S. No. 200	Less than 2 percent

Geotextile Materials

Geotextile material requirements are summarized in Table 17.

TABLE 17. GEOTEXTILE MATERIAL MINIMUM REQUIREMENTS		
Geotextile Property[36]	**Value (Woven/Nonwoven)**	**Test Method**
Grab Tensile Strength, min, in machine and x-machine direction	180 lbs./115 lbs. (min)	ASTM D4632
Grab Failure Strain, in machine and x-machine direction	< 50%/≥ 50%	ASTM D4632
Seam Breaking Strength	160 lbs./100 lbs. (min)	ASTM D4632
Puncture Resistance	67 lbs./40 lbs. (min)	ASTM D4833
Tear Strength, min. in machine and x-machine direction	67 lbs./40 lbs. (min)	ASTM D4533
Burst strength (psi)	130 (min)	ASTM D3786
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60 - #70	ASTM D4751
Ultraviolet resistance	70 percent or greater	ASTM D4355
Notes: Acceptability of geotextile material shall be based on ASTM D-4759. Minimum values should be in the weaker principal direction. All numerical values represent minimum average roll value (i.e., test results from any sampled lot shall meet or exceed the minimum values in the table). Stated values are for noncritical and nonsevere applications. If construction conditions dictate use of a more durable geotextile material to prevent punctures or tearing during installation, a heavier fabric should be used.		

Underdrain Systems

1. Several **underdrain systems** are acceptable:
   - A central collector pipe with lateral feeder pipes in an 8-inch gravel backfill or drain rock bed
   - A central collector pipe with a geotextile drain strip in an 8-inch gravel backfill or drain rock bed
   - Longitudinal pipes in an 8-inch gravel backfill or drain rock bed, with a collector pipe at the outlet end.

     In smaller installations a single perforated pipe in 8 inches of gravel backfill or drain rock may be adequate.
2. The **maximum perpendicular distance** between any two feeder pipes, or the edge of the filter and a feeder pipe, shall be 15 feet.

[36] All geotextile properties are minimum average roll values (i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table). Values for tensile strength, failure strain, seam breaking strength, puncture resistance, and tear strength are from Washington State Department of Transportation, Standard Specifications: 2000. Section 9-33, and are not contained in the King County *Surface Water Design Manual* (1998).

Intent: This spacing is required to prevent the underdrain system from backing up into the sand filter during the early life of the filter when high filtration rates exist.

3. All pipe shall be placed with a **minimum slope** of 0.5%.

4. The **invert of the underdrain outlet** shall be above the seasonal high groundwater level. The *seasonal high groundwater level* is the highest elevation of groundwater observed.

   Intent: The underdrain must be able to remove standing water from beneath the sand. If standing water remains, the sand will remain saturated. This could cause depletion of dissolved oxygen and reducing conditions in the sand, allowing some pollutants to become mobile and be released from the filter to downstream receiving waters.

5. **Cleanout** wyes with caps or junction boxes shall be provided at both ends of all collector pipes. Cleanouts shall extend to the surface of the filter.

   a) A valve box must be provided for access to the cleanouts.

   b) The cleanout assembly must be water tight to prevent short circuiting of the filter.

   Intent: Caps are required on cleanout wyes to prevent short-circuiting of water into the underdrain system when the pond fills with water.

6. If a **drain strip** is used for lateral drainage, the strip must be placed at the slope specified by the manufacturer but at least at 0.5%. All drain strip must extend to the central collector pipe. Drain strips installations must be analyzed for conveyance because manufactured products vary in the amount of flow they are designed to handle.

7. At least 8 inches of **gravel backfill** must be maintained over all underdrain piping or drain strip, and 6 inches must be maintained on either side to prevent damage by heavy equipment during maintenance. Either drain rock or gravel backfill may be used between pipes or drain strip.

   Note: If drain strip is used, it may be easier to install the central collector pipe in an 8-inch ***trench*** *filled with drain rock, making the cover over the drain strip and the collector pipe the same thickness. In this case the pipe shall be wrapped with geotextile to prevent clogging. Use the same geotextile specification as given in* Table 17 (p.120).

8. A **geotextile fabric** shall be used between the sand layer and the drain rock or gravel and be placed so that one inch of drain rock or gravel is above the fabric.

   Intent: The position of the geotextile fabric provides a **transition layer** of mixed sand and gravel or rock. A distinct layer of finely textured sand above a coarser one may cause water to pool at the interface and not readily drain downward due to the greater capillary forces in the finer material.

Underdrain Materials

1. Underdrain **pipe** shall be minimum 6 inch diameter perforated PVC. One acceptable specification for perforations is as follows: 2 rows of holes (1/2-inch diameter) spaced 6 inches apart longitudinally (max), with rows 120 degrees apart (laid with holes downward). Other drain pipe may be used if it adequately drains the filter.

2. **Drain rock** shall be 1½ to 1¾-inch rock or gravel backfill, washed and free from clay or organic material.

3. If a geotextile drain strip system is used, the attached **geotextile fabric** should not be used, or the fabric side should be positioned away from the sand blanket. Geotextile is

already required between the sand and drain rock layers, and must meet the specifications in Table 17 (p. 120) to avoid clogging the filter prematurely.

Access Roads & Setbacks

An access road shall be provided to the inlet and outlet of a sand filter for inspection and maintenance purposes. Requirements for access roads are the same as for wetponds (see page 81) The location of the facility relative to site constraints (e.g., buildings, property lines, etc.) shall be the same as for wetponds (see page 80).

Grass Cover

1. **No top soil** may be added to sand filter beds because fine-grained materials (e.g., silt and clay) reduce the hydraulic capacity of the filter.
2. **Growing grass** will require selecting species that can tolerate the demanding environment of the sand bed. Sand filters experience long periods of saturation during the winter wet season, followed by extended dry periods during the summer. Modeling predicts that sand filters will be dry about 60% of the time in a typical year. Consequently, vegetation must be capable of surviving drought as well as wetness.
   - The grasses and plants listed in Table 18 (below) are good choices for pond sides. They are facultative (i.e., they can tolerate fluctuations in soil water). These species can generally survive approximately 1 month of submersion while dormant in the winter (until about February 15), but they can withstand only about 1 to 2 weeks of submersion after mid-February.
   - The lower portion of Table 18 lists grass species that are good choices for the sand filter bottom. They can withstand summer drying and are fairly tolerant of infertile soils. In general, planting a mixture of 3 or more species is recommended. This ensures better coverage since tolerance of the different species is somewhat different, and the best adapted grasses will spread more rapidly than the others. Legumes, such as clover, fix nitrogen and hence can thrive in low-fertility soils such as sands. This makes them particularly good choices for planting the sand filter bed.
3. A **sport-field sod** grown in sand may be used on the sand surface. No other sod may be used due to the high clay content in most sod soils.
4. To prevent overuse that could compact and potentially damage the filter surface, **permanent structures** (e.g., playground equipment or bleachers) are not permitted. Temporary structures or equipment must be removed for filter maintenance.
5. Low phosphorus **fertilizers** (such as formulations in the proportion 3: 1: 3 N-P-K or less) or a slow-release phosphorus formulation should be used.

TABLE 18. RECOMMENDED PLANTS FOR SATURATED AREAS	
RECOMMENDED PLANTS FOR POND SIDES	
Scientific Name	**Common Name**
Agrostis alba	Redtop
Agrostis palustris	Creeping bentgrass
Alopecurus pratensis	Meadow foxtail
Calamagrostis nutkaensis	Pacific reed grass
Glyceria borealis	Northern mannagrass
Holcus lanatus	Common velvet grass
Poa palustris	Fowl bluegrass
Poa pratensis	Kentucky bluegrass
Juncus acuminatus	Tapertip rush
Juncus effusus	Soft rush
RECOMMENDED PLANTS FOR POND BOTTOM (SAND SURFACE)	
Agrostis tenuis	Colonial bentgrass (Highland strain good)
Buchloe dactyloides	Buffalo grass
Festuca elatior	Tall fescue
Festuca elatior "Many Mustang", "Silverado"	Dwarf tall fescues
Festuca rubra	Red fescue
Lolium perenne	Perennial ryegrass
Zoysia tenuifolia	Korean grass
Trifolium repens	White lawn clover
Note: Other grasses may be used if recommended by a horticultural or erosion control specialist for the specific site.	

Recommended Design Features

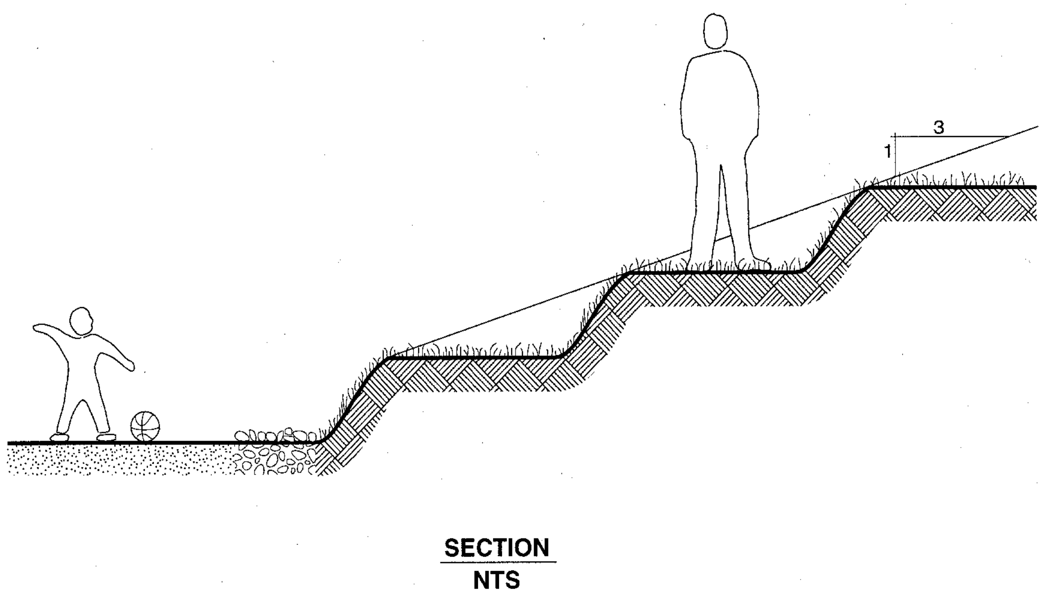
The following design features should be incorporated into sand filter designs where site conditions allow:

1. A **horticultural specialist** should be consulted for advice on planting.
2. **Seed** should be applied in spring or mid to late fall unless irrigation is provided. If the filter is seeded during the dry summer months, surface irrigation is needed to ensure that the seeds germinate and survive. Seed should be applied at 80 lbs./acre.
3. Slow-release **fertilizers** may be applied to improve germination.
4. A sand filter can add landscape interest and should be incorporated into the project **landscape design**. Interior side slopes may be stepped with flat areas to provide informal seating with a game or play area below. Perennial beds can be planted above the

overflow water surface elevation. However, large shrubs and trees are not recommended because shading limits evaporation and can inhibit drying of the filter surface. In addition, falling leaves and needles can clog the filter surface, requiring more frequent maintenance. *Note: Examples of areas with stepped side slopes can be found at the Ballard Locks in Seattle and at Luther Burbank Park on Mercer Island.*

5. If **recreational use** is intended, such as for a badminton or volleyball play area, the interior side slopes of the filter embankment should be no steeper than 3:1.

FIGURE 27. SCHEMATIC OF STEPPED SIDE SLOPES



Construction Considerations

1. If sand filters are put into service before construction of all parcels within the catchment is complete and all disturbed soil in the sand filter catchment has been stabilized, the filter will very likely clog prematurely.

   An **alternative** is to install the sand filter pond including full excavation for the filter sand and underdrain layers, delaying placement of the sand and underdrains until the site is stabilized. The partially complete sand filter will then function like a small wetpond. Later, the accumulated sediment should be cleaned and the underdrain and sand layers placed. A second alternative is to place only the gravel underdrain during the construction phase. Then clean the gravel and place the sand layer after the site is stabilized.

2. **Careful placement of the sand** is necessary to avoid formation of voids within the sand that could lead to short-circuiting, particularly around penetrations for underdrain

cleanouts, as well as to prevent damage to the underlying geomembranes and underdrain system. Voids between the trench wall and geotextile fabric should also be avoided.

3. **Over compaction must be avoided** to ensure adequate filtration capacity. Sand is best placed with a low ground pressure tracked bulldozer (4.6 pounds per square inch or less ground pressure). The number of passes over sand fill should be minimized during placement; using low ground-pressure vehicles can minimize ground pressure and compaction.
4. After the sand layer is placed, water settling is recommended. Flood the sand with 10 to 15 gallons of water per cubic foot of sand.

Maintenance Considerations

Sand filters are subject to clogging by fine sediment, oil and grease, and other debris (e.g., trash and organic matter such as leaves). Filters and pretreatment facilities should be inspected every 6 months during the first year of operation. Inspections should also occur immediately following a storm event to assess the filtration capacity of the filter. Once the filter is performing as designed, the frequency of inspection may be reduced to once per year.

During an inspection the following features should be evaluated and maintained as needed:

1. Remove debris and sediment from the pretreatment facility when depth exceeds 12 inches.
2. Remove debris and sediment from the surface of the filter when accumulations exceed 0.5 inches.
3. Observe operation of the overflow and drawdown time in the filter. Frequent overflow through the grated "birdcage" or "jailhouse" window into the outlet structure or slow drawdown are indicators of plugging problems. Under normal operating conditions, a sand filter should completely empty within 9 to 24 hours following a storm event (i.e., after the inflow of runoff to the filter ceases), depending on pond depth. Generally, if the water level over the filter drops at a rate less than about 1-inch per hour[37] ($V <$ 1-inch per hour), corrective maintenance is needed. Recommendations for improving sand filter performance are summarized below:
    a) Remove thatch accumulation in grass.
    b) Aerate the filter surface to improve permeability.
    c) Till the filter surface. Two separate passes following a crisscross pattern (i.e., second pass at right angles to the first) are recommended.
    d) If media only (i.e., without a grass layer), remove the accumulated fine materials to expose clean underlying media. If grass-covered media, remove accumulated fine material and reestablish grass layer as needed.[38]
4. Experience with sand filters used for stormwater treatment in Austin, Texas, showed that the sand can become clogged every 4 to 10 years, requiring replacement.
5. Rapid drawdown in the filter (i.e., greater than 12 inches per hour) may indicate short-circuiting of the filter media. Inspect the cleanouts on the underdrain pipes and along the base of the embankment for leakage.

[37] Note: The King County *Surface Water Design Manual* (1998) specifies a rate of 1/2-inch per hour.
[38] Note: The King County *Surface Water Design Manual* (1998) specifies to “replace upper 4 to 6 inches of grass and sand.”

6. Formation of rills and gullies on the surface of the filter indicates improper function of the inlet flow spreader or poor sand compaction. Check for accumulation of debris on or in the flow spreader, and refill rills and gullies with sand.

Other maintenance practices that should be employed to ensure proper operation of the sand filter are summarized below:

1. Avoid use of excess fertilizers along the bottom or sides of a landscape sand filter.
2. Avoid driving heavy machinery or equipment on the sand filter to minimize compaction of the filter media and prevent the formation of ruts in the surface of the filter that could concentrate or channelize flow.
3. Mow grass as needed, and remove the cut grass from the sand filter.
4. Water the vegetation periodically when needed, especially during the summer dry season.
5. Discourage use of the sand bed by pets by installing signs reminding residents of scoop laws, planting barriers such as barberry, or providing other measures as appropriate.

FIGURE 28. SAND FILTER WITH LEVEL SPREADER

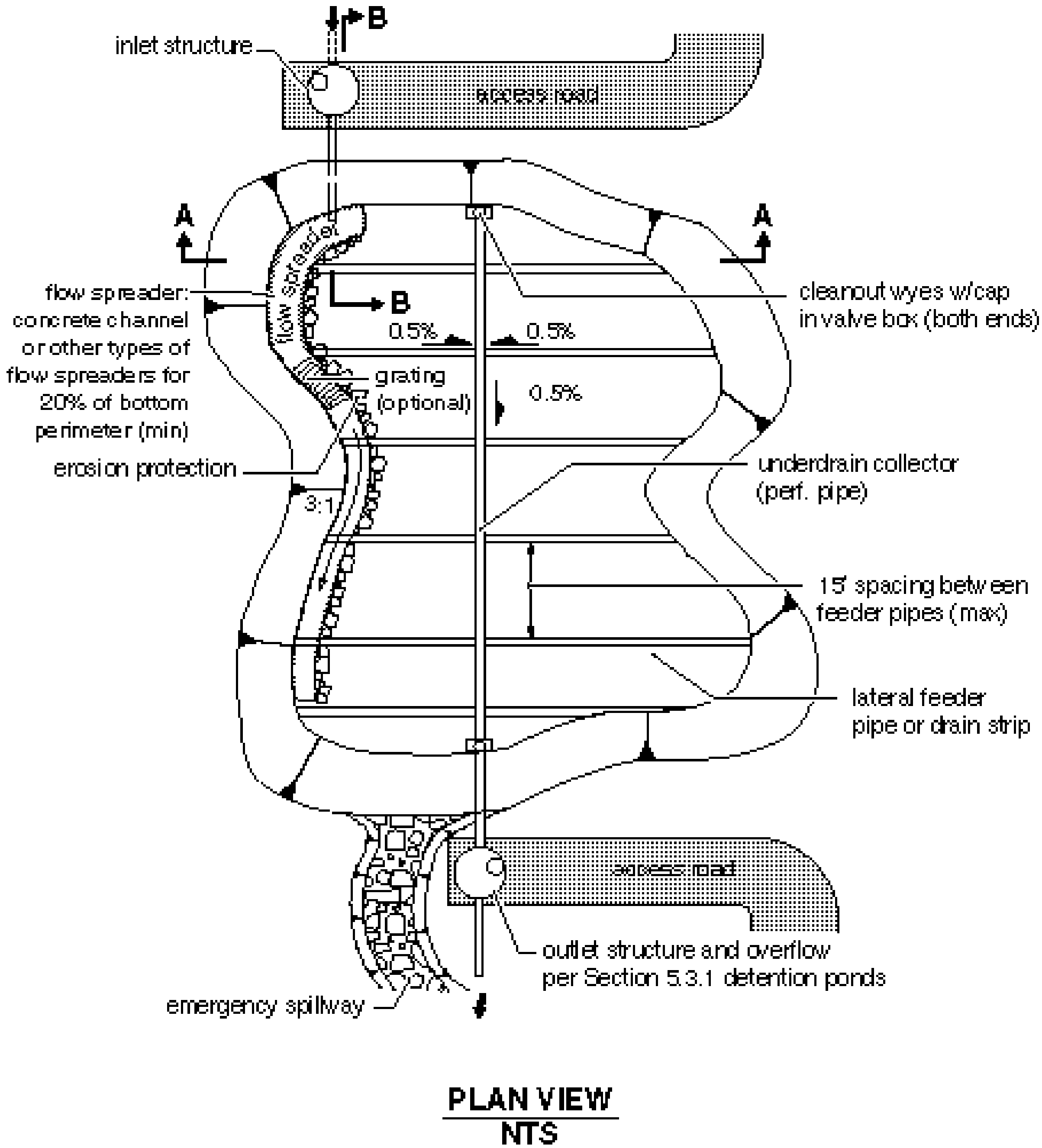
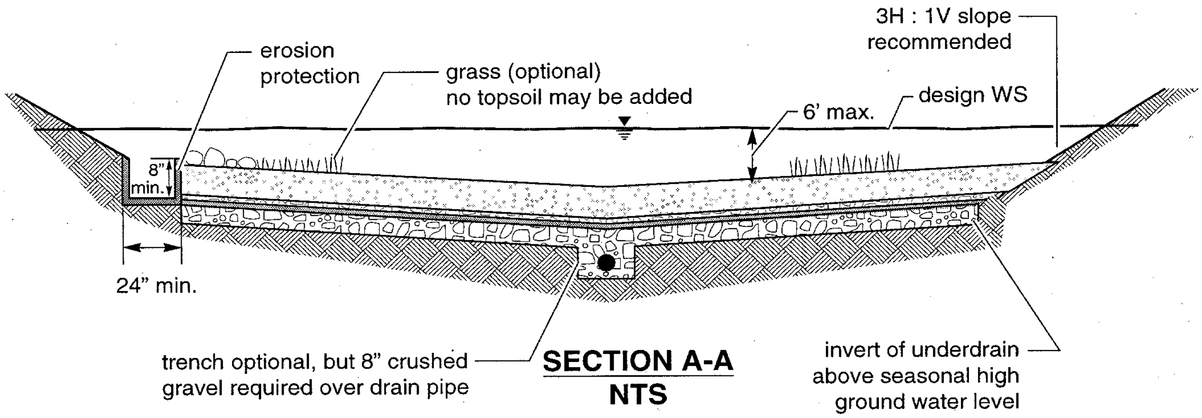


FIGURE 28. SAND FILTER WITH LEVEL SPREADER (*CONTINUED*)



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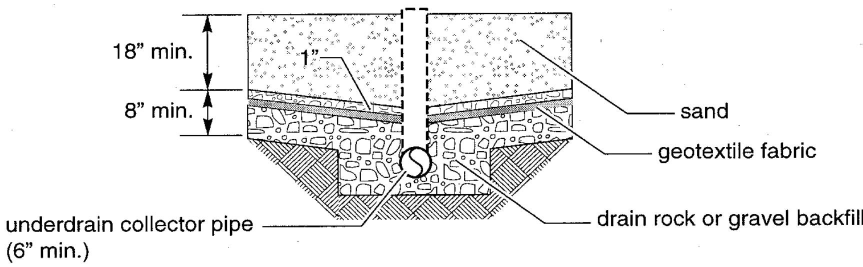

TRENCH DETAIL
NTS

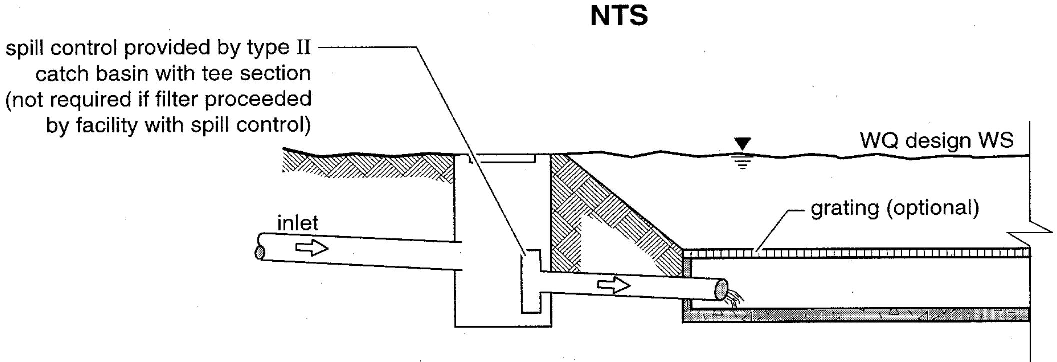

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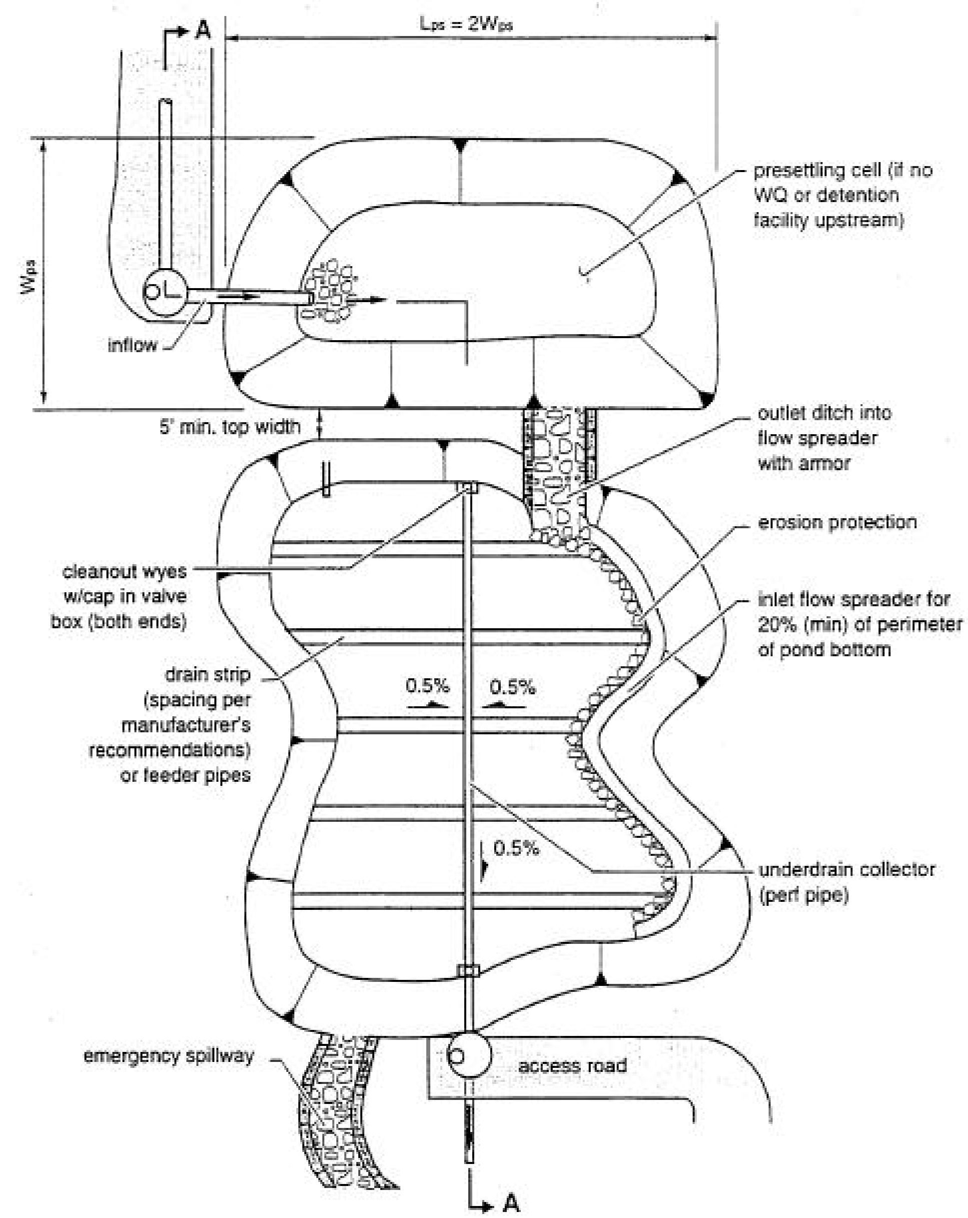
FIGURE 29. SAND FILTER WITH PRETREATMENT CELL



PLAN VIEW
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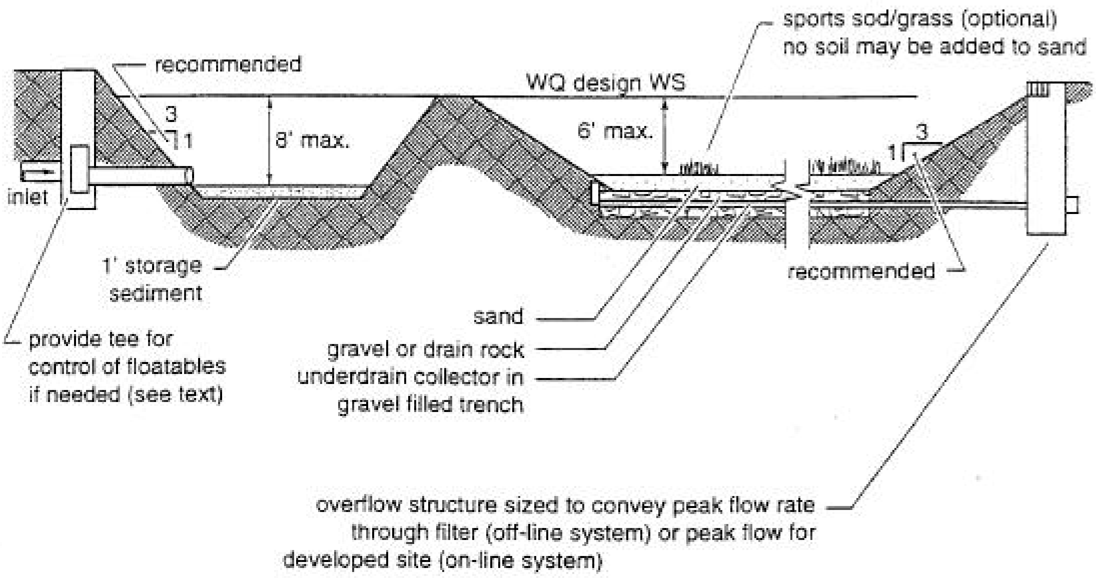
FIGURE 29. SAND FILTER WITH PRETREATMENT CELL (*CONTINUED*)



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5.3 SAND FILTER VAULTS[39]

A *sand filter vault* is similar to an open sand filter except that the sand layer and underdrains are installed below grade in a vault.

Applications and Limitations

A sand filter vault can be used on **sites where space limitations preclude the installation of above ground facilities**. In highly urbanized areas, particularly on redevelopment and infill projects, a vault is a viable alternative to other treatment technologies that require more area to construct.

Like sand filters, sand filter vaults are **not suitable for areas with high water tables** where infiltration of groundwater into the vault and underdrain system will interfere with the hydraulic operation of the filter. Soil conditions in the vicinity of the vault installation should also be evaluated to identify special design or construction requirements for the vault.

It is desirable to have an **elevation difference of 4 feet between the inlet and outlet** of the filter for efficient operation. Therefore, site topography and drainage system hydraulics must be evaluated to determine whether use of an underground filter is feasible.

Because the surface of a sand filter vault is prone to clogging from sediment and other debris, this facility **should not be used in areas where heavy sediment loads are expected**.

5.3.1 Methods of Analysis

The **methods of analysis** for sand filter vaults are identical to the methods described for sand filters. Follow the procedures described in Section 5.2.1 (p. 113).

5.3.2 Design Criteria

In addition to their water quality function, sand filter vaults may serve a conveyance function, passing flows above the water quality design flow through to the downstream drainage system. When used to convey these flows, vaults must meet the conveyance requirements specified in the City of Seattle Directors' Rule for Flow Control and the Stormwater, Grading and Drainage Control Code.

General **design concepts** for sand filter vaults are shown in Figure 30 (p. 135).

Sand Filter Geometry

Same as for sand filters (see page 118).

Pretreatment, Flow-Spreading, and Energy Dissipation

1. See general presettling and pretreatment requirements for filtration facilities, Section 5.1, p. 111.
2. A **flow spreader** shall be installed at the inlet to the filter bed to evenly distribute incoming runoff across the filter and prevent erosion of the filter surface.

[39] Note: The King County *Surface Water Design Manual* (1998) includes specifications for both *basic* and *large* sand filter vaults. The requirements in the Seattle *Stormwater, Grading and Drainage Control Code* can be met by a basic sand filter vault described here.

3. For **vaults with presettling cells**, the presettling cells shall be constructed so that the **divider wall** extends from the floor of the vault to the water quality design water surface and is water tight
4. The flow spreader shall be positioned so that the **top of the spreader** is no more than 8 inches above the top of the sand bed (and at least 2 inches higher than the top of the inlet pipe if a pipe and manifold distribution system is used). See Section 2.5 (p. 27) for details on flow spreaders. For **vaults with presettling cells**, a **concrete sump-type flow spreader** (see Figure 5, p. 31) shall be built into or affixed to the divider wall. The sump shall be a minimum of 1 foot wide and extend the width of the sand filter. The downstream lip of the sump shall be no more than 8 inches above the top of the sand bed.
5. Flows may enter the sand bed by **spilling over the top of the wall into a flow spreader pad**, or alternatively a **pipe and manifold system** may be designed and approved at the discretion of DCLU to deliver water through the wall to the flow spreader. *Note: Water in the first or presettling cell is dead storage. Any pipe and manifold system designed must retain the required dead storage volume in the first cell, minimize turbulence, and be readily maintainable.*
6. If a pipe and manifold system is used, the **minimum pipe size** shall be 8 inches. Multiple inlets are recommended to minimize turbulence and reduce local flow velocities.
7. **Erosion protection** shall be provided along the first foot of the sand bed adjacent to the spreader. Geotextile weighted at the corners with sand bags, quarry spalls, or other suitable erosion control may be used.

Overflow and Bypass Structures

Same as for sand filters (see page 118).

Filter Composition

The filter bed shall consist of three layers as follows:

- Top layer: sand
- Second layer: geotextile fabric
- Third layer: underdrain system.

Sand Specifications and Geotextile Materials

Same as for sand filters (see page 119).

Underdrain Systems and Underdrain Materials

Same as for sand filters (see page 120).

Vault Structure

1. Sand filter vaults are typically designed as on-line (flow-through) systems with a flat bottom under the filter bed.
2. If a presettling cell is provided, the **cell bottom** may be longitudinally level or inclined toward the inlet. To facilitate sediment removal, the bottom shall also slope from each side towards the center at a minimum of 5%, forming a broad "v". *Note: More than one "v" may be used to minimize cell depth.*

Exception: The bottom of the presettling cell may be flat rather than v-shaped if **removable panels** are provided over the entire presettling cell. Removable panels shall be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel.

3. One foot (average) of **sediment storage** must be provided in the presettling cell.
4. Where pipes enter and leave the presettling cell below the water quality design water surface, they shall be **sealed** using a non-porous, non-shrinking grout.
5. If an **oil retaining baffle** is used for control of floatables in the presettling cell, it must conform to the following:
   a) The baffle shall extend from 1 foot above to 1 foot below the water quality design water surface (minimum requirements) and be spaced a minimum of 5 feet horizontally from the inlet.
   b) Provision for passage of flows in the event of plugging shall be provided.
   c) An access opening and ladder shall be provided on both sides of the baffle into the presettling cell.
6. Sand filter vaults shall conform with the **"Materials"** and **"Structural Stability"** criteria specified for **wetvaults** (see page 93). The **arch culvert sections** allowed for wetvaults **may not be used** for sand filter vaults. Free access to the entire sand bed is needed for maintenance.

Access Requirements

Same as for **wetvaults** (see page 93) except for the following **modifications:**

1. A minimum of 24 square feet of **ventilation grate** must be provided for each 250 square feet of sand bed surface area. Grates may be located in one area if the sand filter is small, but placement at each end is preferred. Small grates may also be dispersed over the entire sand bed.

   Intent: Grates are important to allow air exchange above the sand. Poor air exchange will hasten anoxic conditions which may result in release of pollutants such as phosphorus and metals and cause objectionable odors.

Access Roads

An access road shall be provided to the inlet and outlet of a sand filter for inspection and maintenance purposes. Requirements for access roads are the same as for wetvaults (see page 93).

Recommended Design Features

The following design features should be incorporated into sand filter vaults where feasible but are not specifically required:

1. The **floor of the presettling cell** should be **sloped toward the inlet** to allow for sediment accumulation and ease of cleaning.
2. A **geotextile fabric** is recommended over the sand bed to make sand bed maintenance easier. The geotextile fabric can then be removed, cleaned, and replaced on top of the sand media after cleaning. If used, the geotextile should be a flexible, high-permeability, three-dimensional matrix of the kind commonly used for erosion control. Sand bags should be used at 10 to 15 foot intervals to hold the geotextile in place.

3. **Additional grates** are recommended instead of solid panels to increase air contact with the sand bed.
4. **Vault entry** is subject to OSHA requirements for confined spaces, including clearly marking entrances. This may be accomplished by hanging a removable sign in the access riser(s), just under the access lid.

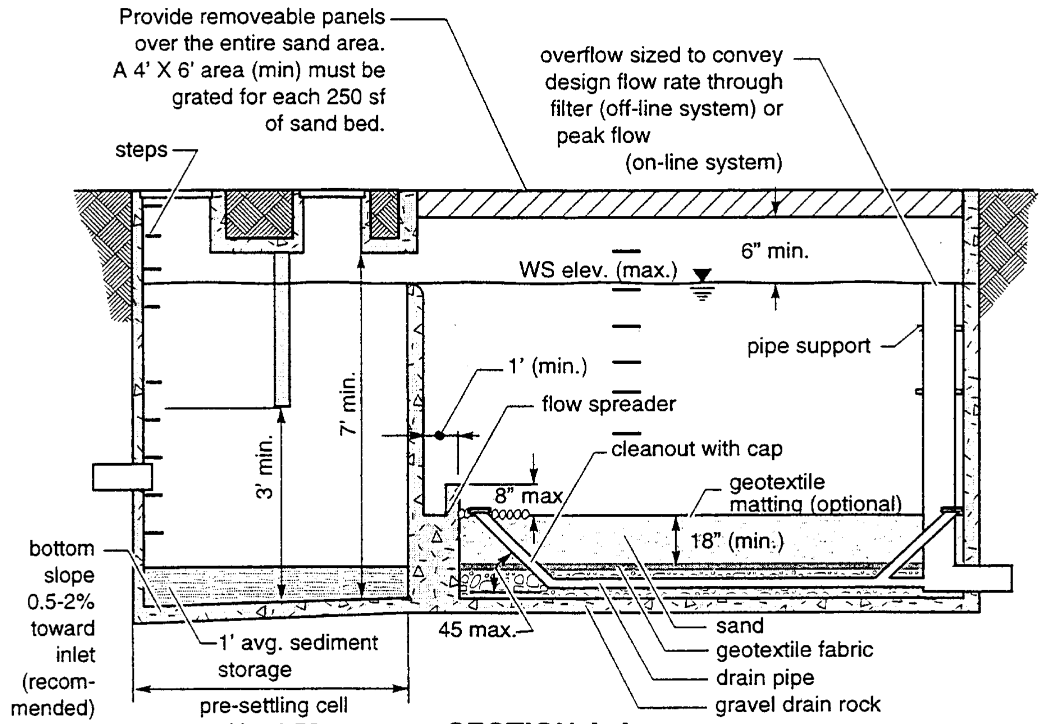
Construction Considerations

Same as for sand filters (see page 124) plus, upon completion of installation, the vault should be thoroughly cleaned and flushed prior to placement of sand and drain rock.

Maintenance Considerations

Maintenance considerations for sand filter vaults are similar to those described in Section 5.2 (p. 113) for sand filters. Note, however, that confined space entry procedures should be followed when entering a vault. Even though some surface ventilation is provided for sand filter vaults, precautions are still warranted.

FIGURE 30. SAND FILTER VAULT



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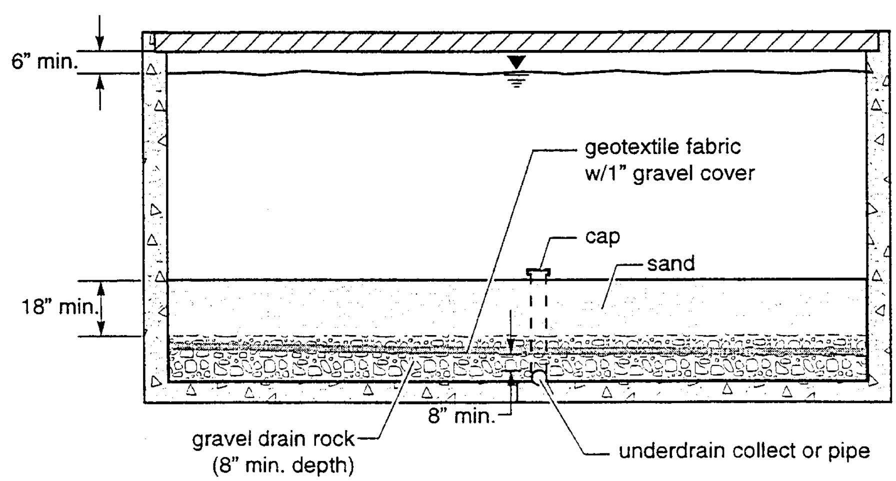

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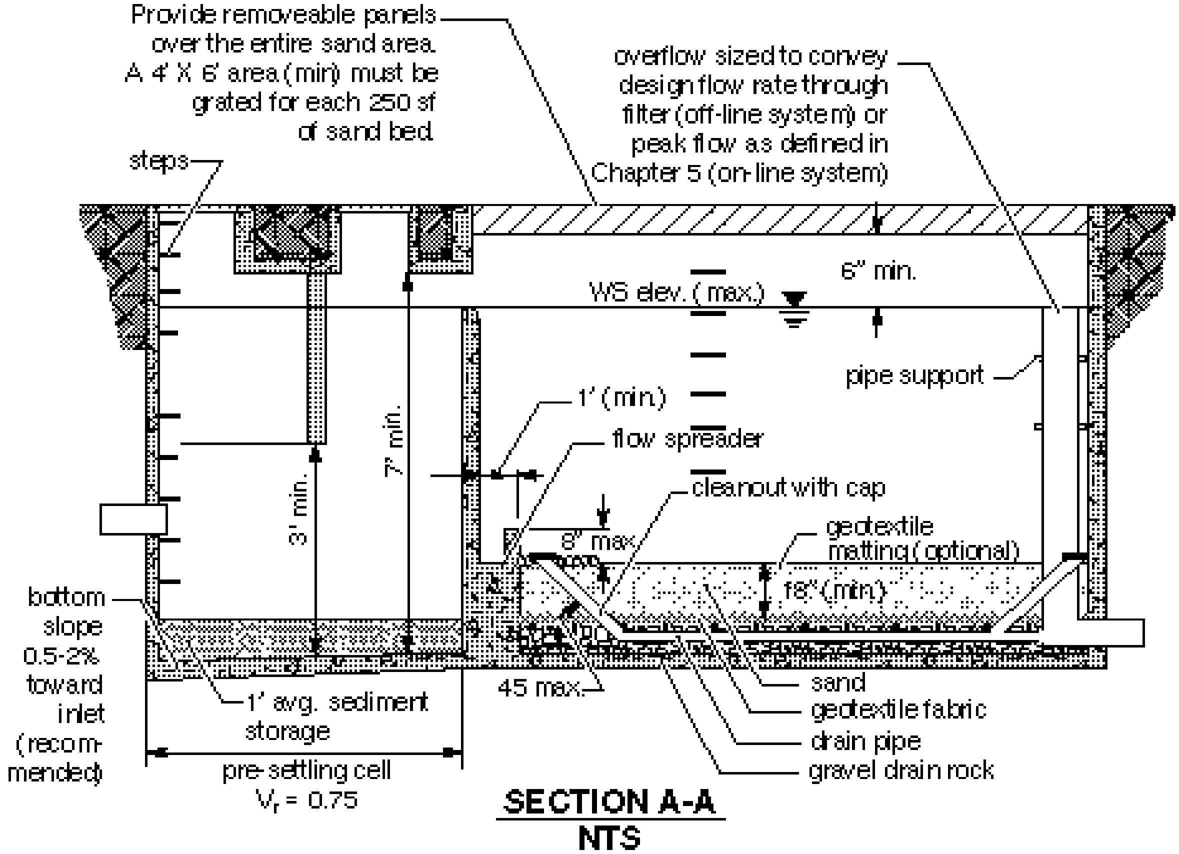
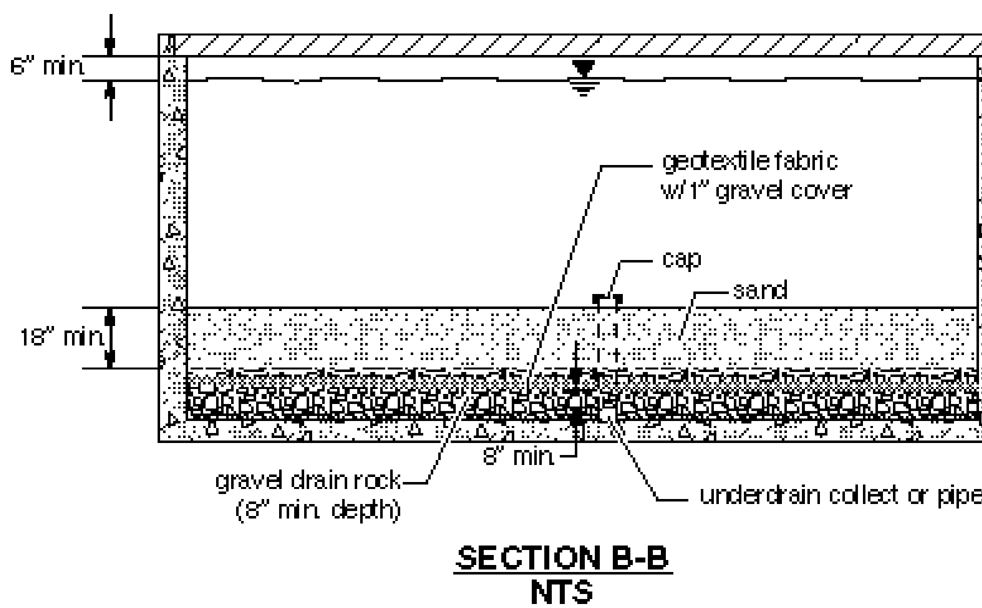
FIGURE 30. SAND FILTER VAULT (*CONTINUED*)





5.4 LINEAR SAND FILTERS[40]

Linear sand filters are typically long, shallow, rectangular vaults. The vaults consist of two cells or chambers, one for settling coarse sediment from the runoff and the other containing sand. Stormwater flows into the second cell via a weir section that also functions as a flow spreader to distribute the flow over the sand. The outlet consists of an underdrain pipe system that connects to the storm drain system.

Applications and Limitations

The linear sand filter is used for stormwater flows for two different treatment purposes:

1. To provide basic or second-tier water quality treatment, and
2. To treat runoff from high-use sites (i.e., sites generating higher than typical concentrations of oil and grease).

Linear sand filters are **best suited for treating small drainages** (less than 5 acres), particularly long, narrow areas. The goal is to keep linear sand filters fairly shallow and narrow in width. A linear sand filter can be located along the perimeter of a paved impervious surface or can be installed downstream of a filter strip where additional treatment is needed. If used for oil control, the filter should be located upstream from the main stormwater quality treatment facility (e.g., wetpond, biofiltration swale, or combined detention and wetpond).

5.4.1 Methods Of Analysis

A linear sand filter is sized based on the infiltration rate of the sand and the amount of runoff draining to the facility. The filter is sized to infiltrate the sand filter design flow without significant ponding above the sand.

Step 1: Determine the rainfall region and regional scale factor. Regional scale factors are used to account for differences in rainfall between different rainfall gauging stations. For the Seattle area, use a scale factor of 1.0.

Step 2: Determine site characteristics. Determine the total number of impervious acres and the total number of grass acres draining to the sand filter. Determine whether the site is on till or outwash soils. Refer to Table 10 on page 72 to determine which soil types are considered till and which are considered outwash.

Step 3: Calculate the minimum required surface area for the linear sand filter. Determine the sand filter area by multiplying the values in Table 19 (p.138) by the site acreage from Step 3 using the following equation:

$$A_{sf} = 0.7\, C_s\, (T_i A_i + T_{tg} A_{tg} + T_{og} A_{og}) \qquad (5\text{-}5)$$

where

A_{sf}	=	sand filter area (sf)
0.7	=	adjustment factor to account for routing effect on size
C_s	=	regional scale factor (unitless) from Step 2
$T_{i,tg,\ og}$	=	tributary area per soil/cover type (acres)

[40] Note: The King County *Surface Water Design Manual* (1998) includes specifications for both *basic* and *large* linear sand filter strips. The requirements in the Seattle *Stormwater, Grading and Drainage Control Code* can be met by a basic sand filter strip described here.

$A_{i,tg,\ og}$ = filter area per soil/cover type (sf/acre) from Table 19.

The values in Table 19 (below) are identical to those in Table 15 for the simple sizing method but are repeated below for convenience. For depths less than 1 foot, a detailed routing method must be used.

Linear sand filters may also be sized using the detailed routing procedures. It is expected that filters designed with the detailed routing method would be narrower than those sized using Table 19.

Step 4: Size the sediment cell. The sediment cell width should be set after the sand filter width is determined. Use Table 20 below to set the width of the sediment cell. If another stormwater treatment facility precedes the sand filter, the sediment cell may be waived.

Note: For background on the derivation of numbers in Table 19 refer to the "Background" discussion (p. 114) for the sand filter.

TABLE 19. LINEAR SAND FILTER AREA INCREMENTS FOR SEATAC

		Soil/Cover Types [filter area (sf) / tributary area (acres)]		
Region and Treatment Goal	**Max. Water Depth (ft)**	A_i **Impervious**	A_{fg} **Till grass**	A_{og} **Outwash grass**
SeaTac Basic	1	1711	360	314

TABLE 20. SEDIMENT CELL WIDTH, LINEAR SAND FILTER

If Sand filter width is:	**Width of sediment cell should be:**
1 to 2 feet	12 inches
2 to 4 feet	18 inches
4 to 6 feet	24 inches
Over 6 feet	One-third of sand cell width

Example

A site in the City of Seattle has 1 acre of impervious area and 0.2 acres of till grass draining to the sand filter (1 foot of head above the filter). The designer wants to install a linear sand filter along a 200-foot parking area. The required sand area for a basic size linear sand filter would be found as follows:

Site Areas		Table 19. values for SeaTac, basic size		
1 acres	x	1711 sf/acre	=	1711 sf
+ 0.2 acres	x	360 sf/acre	=	72 sf
			=	1783 sf

Because the site is located in Seattle, the "regional scale factor" is 1.0. Multiply the 2700 square feet by the 0.7 adjustment factor. Multiply the result by the 0.7 adjustment factor.

1783 sf x 1.0 x 0.7 = 1248 sf

The required sand bed area is therefore **1248 square feet.** Divide 1248 square feet by 200 feet, the length of the filter for the site, to get a required sand bed width of 6.2 feet. The sediment cell would be one-third of 6.2 feet, or about 2 feet.

Note: To save space, the designer could cover the sand filter with grating that would bear traffic load and use the space for parking. The designer could also hire an engineer to perform the KCRTS detailed routing method. With this method, the sand bed width could be reduced to about 5 feet.

5.4.2 Design Criteria

Linear sand filter details are shown in Figure 31 (p. 141).

Geometry, Sizing, and Overflow

1. A linear sand filter shall consist of **two cells** or chambers, a sediment cell and a sand bed cell, divided by a low divider wall. If the sand filter is preceded by another stormwater treatment facility, and the flow enters the sand filter as sheet flow, the sediment cell may be waived.
2. Stormwater may enter the sediment cell by sheet flow or via a piped inlet.
3. **Minimum inside width** of the sand filter cell shall be 1 foot. **Maximum width** shall be 15 feet.
4. The **divider wall** must be level and extend 12 inches (max) above the sand bed.
5. The **sand filter bed** shall be 12 inches deep. An 8-inch layer of **drain rock with perforated drainpipe** shall be installed beneath the sand layer.
6. The **drainpipe** shall have a minimum diameter of 6 inches and be wrapped in **geotextile** and sloped 0.5% (min) to drain.
7. For design, the **maximum depth of ponding** over the sand shall be 1 foot.

8. If separated from traffic areas, a linear sand filter may be **covered or open**, but if covered, the cover must be removable for the entire length of the filter. Covers must be grated if flow to the filter is from sheet flow.
9. A linear sand filter shall have an **emergency overflow route**, either surface overland, tightline, or other structure for safely controlling the overflow, and shall meet the conveyance requirements specified in Chapter 1.

Structure Specifications

1. A linear sand filter vault shall be concrete (precast/prefabricated or cast-in-place). The concrete must conform to the **"Material"** requirements for **wetvaults** (see page 93).
2. At the discretion of DCLU, the sediment cell may be made of materials other than concrete, provided water can be evenly spread for uniform delivery into the sand filter cell.
3. Where linear sand filters are located in traffic areas, they must meet the **"Structural Stability"** requirements specified for **wetvaults** (see page 93). The sediment cell shall have a **removable grated cover** that meets HS-25 traffic loading requirements. The cover over the sand filter cell may be either solid or grated.
4. A minimum of 24 square feet of **ventilation grate** must be provided for each 250 square feet of sand bed surface area. Grates located over the sediment chamber are preferred. Grates may be in one central location or dispersed over the entire sand bed. Vertical grates may also be used, such as at a curb inlet.

   Intent: Grates are important to allow air exchange above the sand. Poor air exchange will hasten anoxic conditions which may result in release of pollutants such as phosphorus and metals and cause objectionable odors.

Sand Specifications

Same as for sand filters (see Table 16, p. 119).

Geotextile Materials

Same as for sand filters (see **Error! Reference source not found.**, p. 120).

Underdrain Materials

Same as for sand filters (see page 121).

Access Roads

Same as for wetvaults (see page 93)

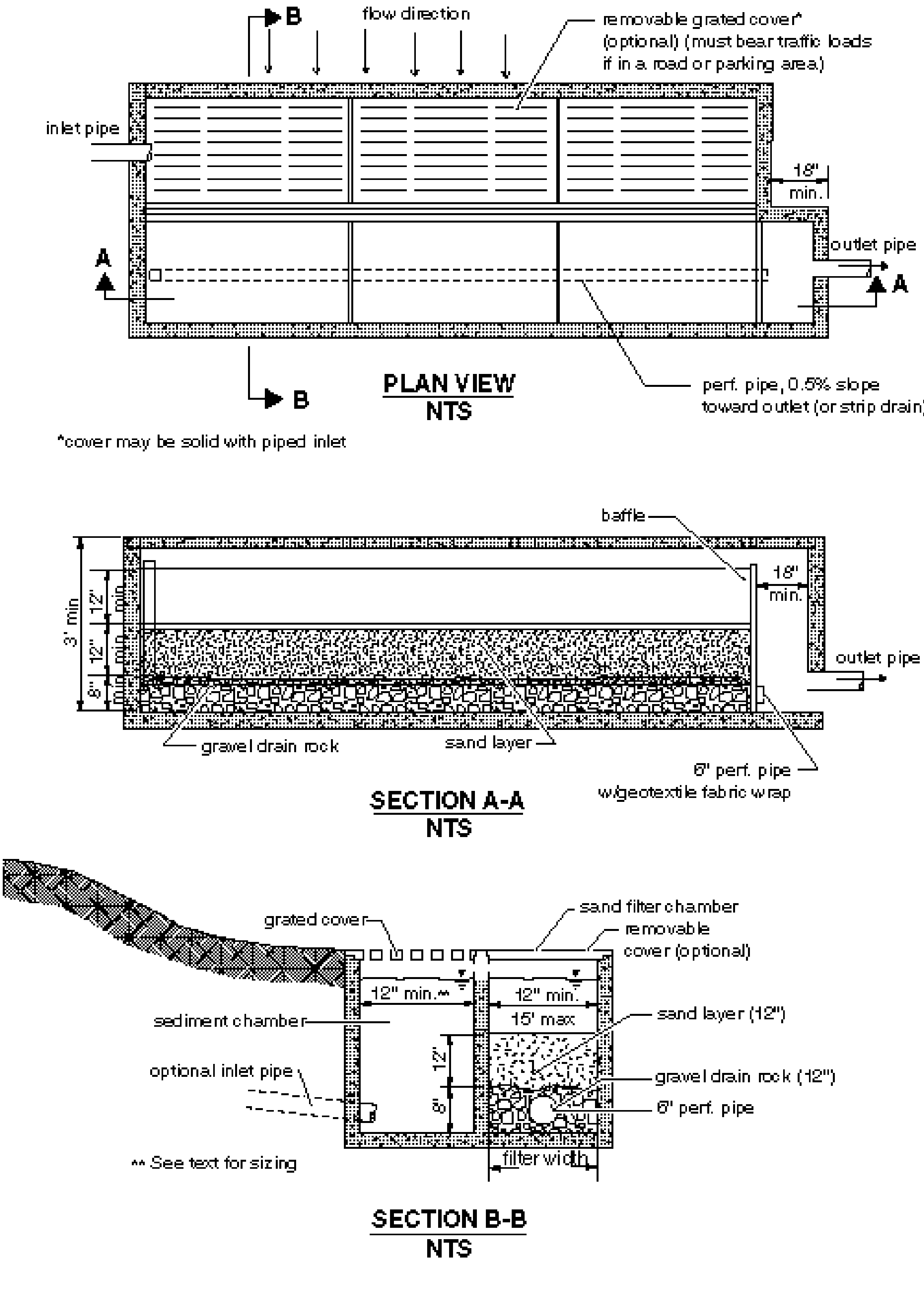
Construction Considerations

If put into service before the site is stabilized, placement of the sand layer should be delayed, and the linear sand filter may be used with the gravel layer only. The gravel layer must be replaced and the vault cleaned when the site is stabilized and the sand bed installed.

Maintenance Considerations

Maintenance considerations for linear sand filters are similar to those for sand filters (see Section 118) except sediment should be removed from the sediment cell when the depth exceeds 6 inches.

FIGURE 31. LINEAR SAND FILTER



5.5 STORMFILTER™

The process and apparatus of treating stormwater runoff by passing the runoff through leaf compost material is patented (Patent Number 5,322,629) by Stormwater Management, a company based in Portland, Oregon. A Stormfilter™ removes pollutants through filtration, ion exchange, adsorption, and microbial degradation. Filter media other than leaf compost are is also available. Figure 32 (p. 144) gives a schematic representation of a Stormfilter™.

Applications and Limitations[41]

Stormfilters™ can be especially effective in situations where removal of metal contaminants is desired.

5.5.1 Methods of Analysis

Stormfilter™ sizing is based on the water quality design flow (see Section 2.1, p. 11). Since the process and the filter media are patented, Stormwater Management personnel will configure a filter based on the design flow provided and specific site characteristics. An accurate description of land use and potential sediment and pollutant loading sources shall also be provided to Stormwater Management personnel, who consider these factors in sizing. The typical size of the precast unit can be estimated based on the water quality design flow in Table 21 (below).

TABLE 21. TYPICAL PRECAST FILTER VAULT SIZES BASED ON DESIGN FLOW

Design Flow (cfs)	Vault Size[42]
up to 0.17	6' x 8'
0.18 to 0.30	6' x 12'
0.31 to 0.60	8' x 14'
0.61 to 1.0	8' x 18'
greater than 1.0	multiple precast vaults or cast in place

5.5.2 Design Criteria

Figure 32 (p. 144) illustrates the general configuration of a typical Stormfilter™ unit using standard precast concrete vaults.

General

Vaults used for a Stormfilter™ shall conform with the **"Materials"** and **"Structural Stability"** criteria specified for **wetvaults** (see page 93).

[41] The King County *Surface Water Design Manual* (1998) does not allow a STORMFILTER™ structure to be used as a stand-alone stormwater treatment facility. The Seattle *Stormwater, Grading and Drainage Control Code* contains no such limitation, provided that presettling is provided before stormwater enters the filtration system (see Section 5.1).

[42] Note: Some vault sizes may be changed or discontinued by the vendor.

Pretreatment

Providing adequate pretreatment and is the key to obtaining an adjustment approval. See Section 5.1, p. 111 for general pretreatment requirements.

Access Requirements

1. Unobstructed **access must be provided over the entire vault floor** by either access doors or removable panels to allow for removal and replacement of the filter cartridges. Removable panels, if used, shall be at grade, have stainless steel lifting eyes, and weight no more than 5 tons per panel.
2. Access to the **inflow and outlet cells** must also be provided.
3. **Ladder access** is required when vault height exceeds 4 feet.
4. All **access openings,** except those covered by removable panels, shall have round, solid **locking lids,** or 3-foot square, locking diamond plate covers.

Access Roads, Right of Way, and Setbacks

Same as for detention vaults (see page 94).

Construction Considerations

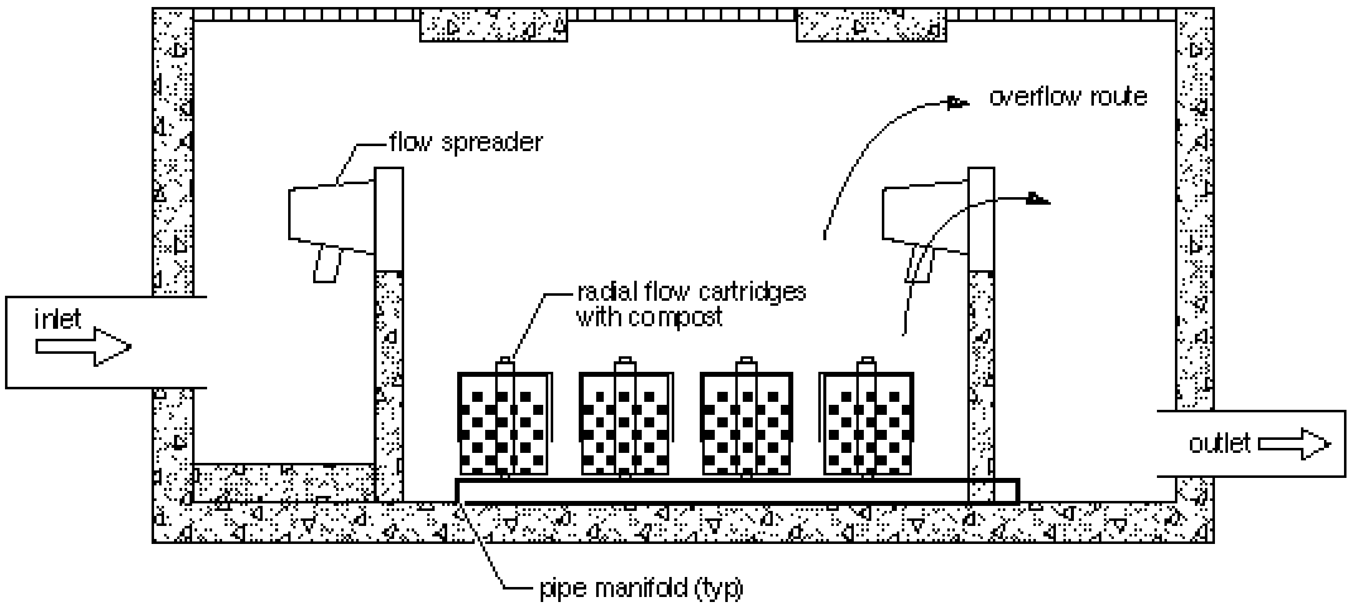
Installation of a Stormfilter™ shall follow the manufacturer's recommended procedures.

Maintenance Requirements

Maintenance needs vary from site to site based on the type of land use activity, implementation of source controls, and weather conditions. Stormfilters™ shall be inspected quarterly or at a frequency recommended by the supplier. Inspection and maintenance shall include the following:

1. The operation and maintenance instructions from the manufacturer shall be kept along with an inspection and maintenance log. The **maintenance log** shall be available for review by City inspectors.
2. **Routine maintenance** shall include inspecting for debris, vegetation, and sediment accumulation, flushing the underdrain, and removing or replacing compost media.
3. **Sediment** shall be removed when the accumulation causes the infiltration capacity to drop below the design flow rate of 15 gpm per filter cartridge. *Note: Instructions are available from the manufacturer for testing infiltration capacity.*
4. The **compost media** should be replaced at least once a year or when infiltration capacity is unrecoverable. Sediment removal and/or compost media replacement may require a vactor truck, but more typically is removed in the dry with a square-point shovel.
5. Media shall be disposed of in accordance with applicable regulations, including the Seattle-King County Department of Public Health solid waste regulations (Title 10) and state dangerous waste regulations (WAC 173-303). In most cases, compost media may be disposed of as solid waste.

FIGURE 32. *STORMFILTER™* SCHEMATIC



U.S. Patent No. 5,322,629

6 OIL CONTROL FACILITY DESIGNS[43]

This section presents the methods, criteria, and details for oil control facilities. The information presented for each facility is organized into the following two categories:

1. **Methods of Analysis:** Contains a step-by-step procedure for designing and sizing each facility. Information used in the procedure is based on available literature, but clarified or modified where deficiencies were identified.[44]
2. **Design Criteria:** Contains the details, specifications, and material requirements for each facility.

6.1 OIL/WATER SEPARATORS

Oil/water separators rely on passive mechanisms that take advantage of oil being lighter than water. Oil rises to the surface and can be periodically removed. The two types of oil/water separators typically used for stormwater treatment are the baffle type or API (American Petroleum Institute) oil/water separator and the coalescing plate oil/water separator.

Baffle(API) oil/water separators use vaults that have multiple cells separated by baffles extending down from the top of the vault (see Figure 36 on page 158 for schematic details). The baffles block oil flow out of the vault. Baffles are also commonly installed at the bottom of the vault to trap solids and sludge that accumulate over time. In many situations, simple floating or more sophisticated mechanical oil skimmers are installed to remove the oil once it has separated from the water.

Coalescing plate separators are typically manufactured units consisting of a baffled vault containing several inclined corrugated plates stacked and bundled together (see Figure 37 on page 159 for schematic details). The plates are equally spaced (typical plate spacing ranges from 1/4-inch to 1 inch) and are made of a variety of materials, the most common being fiberglass and polypropylene. Efficient separation results because the plates reduce the vertical distance oil droplets must rise in order to separate from the stormwater. Once they reach the plate, oil droplets form a film on the plate surface. The film builds up over time until it becomes thick enough to migrate upward under the influence of gravity along the inclined plate. When the film reaches the edge of the plate, oil is released as large droplets which rise rapidly to the surface, where the oil accumulates until the unit is maintained. Because the plate pack increases treatment effectiveness significantly, coalescing plate separators can achieve a specified treatment level with a smaller vault size than a simple baffle separator.

Oil/water separators are meant to treat stormwater runoff from more intensive land uses, such as high-use sites, and facilities that produce relatively high concentrations of oil and grease. Although baffle separators historically have been used to remove larger oil droplets (150 microns or larger), they can also be sized to remove smaller oil droplets.

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[43] The King County *Surface Water Design Manual* (1998) includes specifications for catch basin inserts and for modified wetvaults to meet oil control facility requirements. Neither of these system is included by the Seattle *Stormwater, Grading and Drainage Control Code and are not, therefore, included in this Manual:*

[44] Such modifications were often based on computer modeling using the King County Runoff Time Series (KCRTS) model. Less frequently they were based on bench-scale studies.

Applications and Limitations

Oil/water separators are designed to remove free oil and are not generally effective in separating oil that has become either chemically or mechanically emulsified and dissolved in water. Therefore, it **is desirable for separators be installed upstream of facilities and conveyance structures that introduce turbulence and consequently promote emulsification**. Emulsification of oil can also result if surfactants or detergents are used to wash parking areas that drain to the separator. Detergents should not be used to clean parking areas unless the wash water is collected and disposed of properly (usually to the sanitary sewer).

Oil/water separators are best located in areas where the tributary drainage area is nearly all impervious, and a fairly high load of petroleum hydrocarbons is likely to be generated. Oil/water separators are not recommended for areas with very dilute concentrations of petroleum hydrocarbons since their performance is not effective at low concentrations. Excluding unpaved areas helps to minimize the amount of sediment entering the vault, reducing the need for maintenance. A unit that fails to function can release previously trapped oil to the downstream receiving water, both in release from the oily sediments and from entrainment of surface oils.

6.1.1 Methods of Analysis

Background

Generally speaking, in most oil and water mixtures the degree of oil/water separation that occurs is dependent on both the time the water is detained in the separator and the oil droplet size. The sizing methods in this section are based on Stokes' law:

$$V_T = \frac{g\left(d_p - d_c\right)D_o^2}{18m} \quad (6\text{-}1)$$

where
- V_T = rise velocity of oil droplet
- g = gravitational constant
- d_p = density of droplet to be removed
- d_c = density of carrier fluid
- D_o = diameter of oil droplet
- m = absolute viscosity of carrier fluid

1. The basic assumptions inherent in Stokes' law are: (1) flow is laminar, and (2) the oil droplets are spherical.

Traditional baffle separators are designed to provide sufficient hydraulic residence time to permit oil droplets to rise to the surface. The residence time T_r is mathematically expressed as follows:

$$T_r = \frac{V}{Q} \quad (6\text{-}2)$$

where
- V = effective volume of the unit or container, or $A_s \ x \ H$, where
- A_s = surface area of the separator unit, and
- H = height of water column in the unit

Q = hydraulic capacity or flow through the separator

The time required for the oil droplet to rise to the surface within the unit is found by the relation:

$$T_T = \frac{H}{V_T} \qquad (6\text{-}3)$$

where V_T = rise velocity of the oil droplet

The oil droplet rises to the water surface if the residence time in the separator is at least equal to the oil droplet rise time. This can be expressed as follows:

$$T_r = T_T$$

By substituting terms and simplifying:

$$V_T = \frac{Q}{A_s} \qquad (6\text{-}4)$$

where A_s = surface area of the separator unit

The ratio in Equation (6-4) is designated as the surface overflow rate or loading rate. It is this rate that governs the removal efficiency of the process and predicts whether an oil droplet will be removed by the separator.

Method for Baffle Separators

Design steps for the baffle separator are summarized below:

Step 1: Determine the water quality design flow (*Q*). The facility is sized based on the water quality design flow (see Section 2.1, p. 11). The separator **must be designed as an off-line facility**. That is, flows higher than the water quality design flow must bypass the separator.

Step 2: Calculate the minimum vertical cross-sectional area. Use the following equation:

$$A_c = \frac{Q}{V_H} \qquad (6\text{-}5)$$

where A_c = minimum cross-sectional area (sf)
Q = water quality design flow (cfs)
V_H = design horizontal velocity (fps)

Set the horizontal velocity V_H equal to 15 times the oil droplet's rise rate V_T. A **design rise rate of 0.033 feet per minute shall be used** unless it is demonstrated that conditions of the influent or performance function warrant the use of an alternative value. Using the 0.033 feet per minute rise rate results in V_H = 0.008 fps (= 0.495 fpm).

Step 3: Calculate the width and depth of the vault. Use the following equation:

$$D = \frac{A_c}{W} \tag{6-6}$$

where D = maximum depth (ft)
W = width of vault (ft)
and where A_c is from Step 2 above.

The computed depth D must meet a depth-to-width ratio r of between 0.3 and 0.5 (i.e., $0.3 \le D/W \le 0.5$).

Note: $D = (r\,A_c)^{0.5}$ and
$W = D/r$ and
r = the depth-to-width ratio

Step 4: Calculate the length of the vault. Use the following equation:

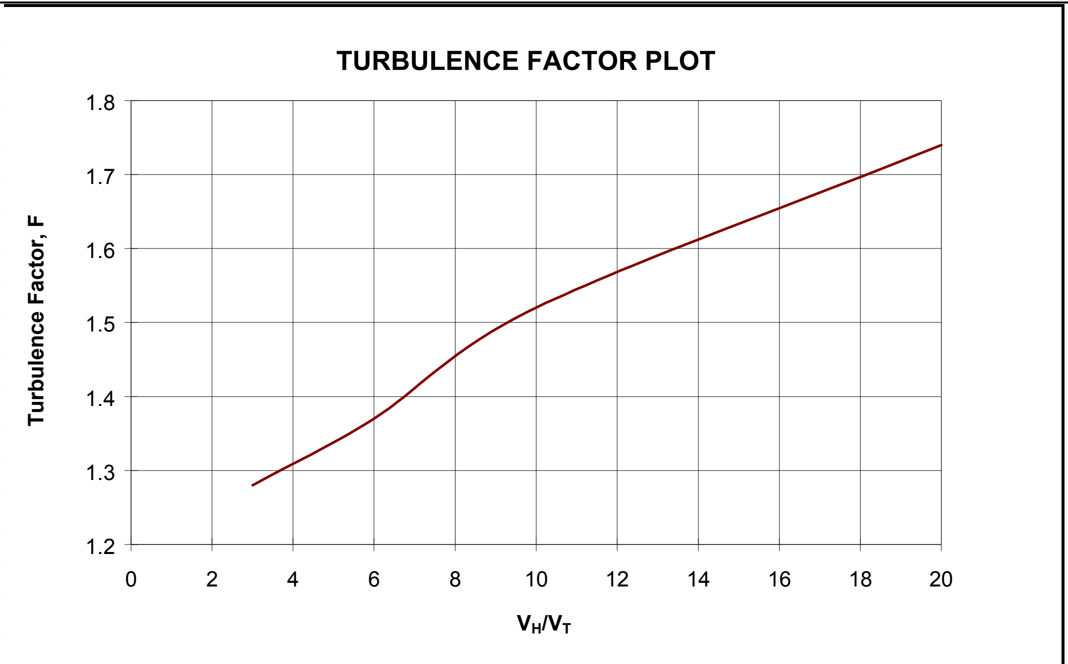
$$L = FD\left(\frac{V_H}{V_T}\right) \tag{6-7}$$

where L = length of vault (ft)
F = turbulence and short-circuiting factor (unitless, see Figure 33)
V_H = horizontal velocity (ft/min)
V_T = oil droplet rise rate (ft/min)
D = depth (ft)

The turbulence factor F should be selected using a V_H/V_T ratio of 15, so $F = 1.64$.

Therefore Equation (6-7) becomes: $L = 1.65 \times 15 \times D$

FIGURE 33. TURBULENCE FACTOR PLOT



Step 5: Check the separator's length-to-width ratio. The length *L* of the vault must be at least 5 times its width in order to minimize effects from inlet and outlet disturbances. The length of the forebay shall be approximately *L*/3.

Step 6: Compute and check that the minimum horizontal surface area (A_H) criterion is satisfied. This criterion is expressed by the following equation:

$$A_H = \left(\frac{1.65Q}{0.00055}\right) \leq LW \tag{6-8}$$

Step 7: Compute and check that the horizontal surface area of the vault forebay. This area must be greater than 20 square feet per 10,000 square feet of tributary impervious area. The length of the forebay (*L*/3) may be increased to meet this criterion without having to increase the overall length of the vault.

Step 8: Design the flow splitter and high-flow bypass. See Section 2.5 (p. 23) for information on flow splitter design.

Method for Coalescing Plate Separators

Coalescing plate separators are designed using the same basic principles as baffle separators. The major difference is that in the baffle separator, horizontal separation is related only to water surface area, while in the coalescing plate separator, horizontal separation is related to the sum of the plan-areas of the plates. The treatment area is increased by the sum of the horizontal projections of the plates being added, and is referred to as the plate *effective separation area*.

The basic procedure for designing a coalescing plate separator is to determine the effective separation area required for a given design flow. The specific vault sizing then depends on the manufacturer's plate design. The specific design, analysis, configuration, and specifications for coalescing plates are empirically based and variable. Manufacturers' recommendations may be used to vary the recommendations given below.

Step 1: Determine the water quality design flow. The coalescing plate oil/water separator must be sized based on the water quality design flow (see Section 2.1, p. 11). The separator **must be designed as an off-line facility**; flows higher than the water quality design flow must bypass the separator.

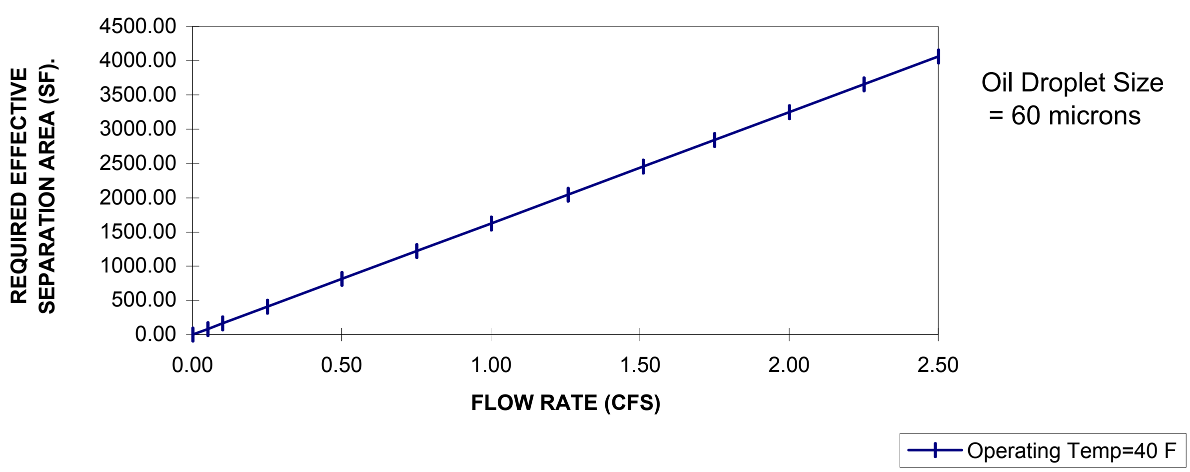
Step 2: Calculate the plate minimum effective separation area (A_h). A_h is found using the following equation:

$$A_h = \frac{60Q}{0.00386\left(\dfrac{S_w - S_o}{m}\right)} \tag{6-9}$$

where
- S_w = specific gravity of water = 1.0
- S_o = specific gravity of oil = 0.85
- m = absolute viscosity of water (poises); use 0.015674 for temp = 39° F
- Q = water quality design flow rate (cfs)
- A_h = required effective (horizontal) surface area of plate media (sf).

Equation (6-9) is based on an oil droplet diameter of 60 microns. A graphical relation of Equation (6-9) is shown in Figure 34 below. This graph may be used to determine the required effective separation surface area of the plate media.

FIGURE 34. EFFECTIVE SEPARATION SURFACE VERSUS FLOW RATE



Step 3: Calculate the collective projected surface area (A_p). A key design step needed to assure adequate performance of the separator unit is to convert the physical plate area (the surface

area of the plates if laid flat) into the effective (horizontal) separation surface area A_h (calculated in step 2). The effective separation surface area A_h is based on the collective projected horizontal surface area A_p of the plates where the plates are inclined, rather than their laid flat.

$$A_h = A_p = A_a (\cos H) \qquad (6\text{-}10)$$

where A_a = actual collective plate area of the plate configuration (sf)
H = angle of the plates to the horizontal (degree)

This equation is represented graphically in Figure 35 below. The designer should make sure that the manufacturer sizes the oil/water separator using the projected surface area rather than the actual plate area. *Note: For this method, only the* ***lower plate surface*** *may be counted as effective separation surface, regardless of manufacturer's claims.*

Step 4: Check with specific separator manufacturers. Check with specific manufacturers to choose a separator that provides the required actual collective plate area calculated in Step 3, and meets the other design criteria given in the next section, beginning on page 153. The specific vault design will depend upon each manufacturer's design. The geometric configuration and dimensions of the plate pack as well as the vault design are variable and flexible depending on each manufacturer's product.

Table 22 (p. 152) provides approximate vault sizes for rough planning purposes. In reality, various manufacturer's have quite different designs, both for the plate packs themselves as well as for forebay and afterbays. In addition, standard pre-cast vault dimensions vary with each manufacturer. These various factors can greatly affect the volume of vault needed to provide a given effective separation area. The numbers in Table 22 should, then, be considered "order of magnitude" estimates only.

FIGURE 35. HORIZONTAL PLATE AREA FOR COALESCING PLATE OIL/WATER SEPARATOR

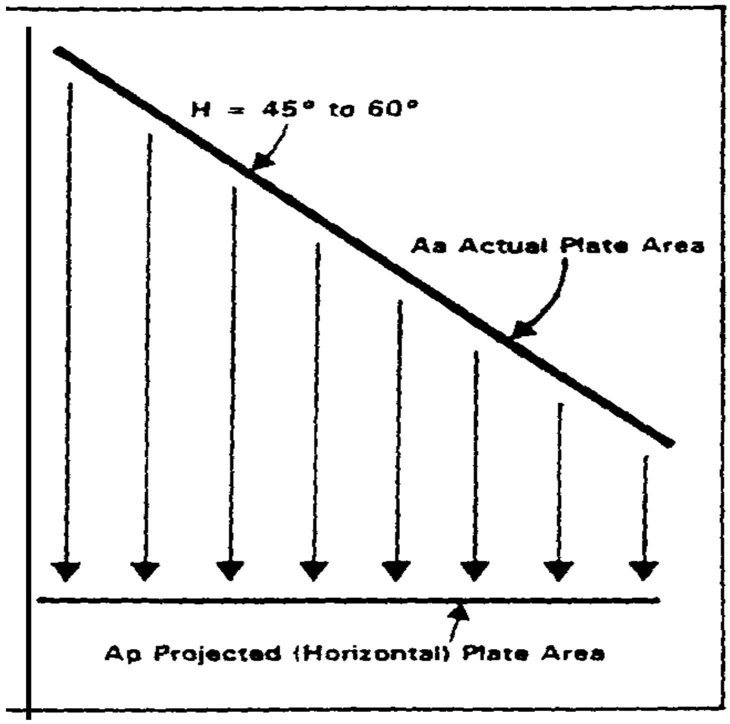


TABLE 22 APPROXIMATE COALESCING PLATE OIL/WATER SEPARATOR VAULT DIMENSIONS	
Area of Effective Separation (square feet)	**Approximate vault volume required (cubic feet) for plates with 1/2 inch spacing and inclined 60 degrees from horizontal (cubic feet)**
100	150
200	240
300	330
600	530
1,200	890
2,400	1150
3,200	2090
4,800	2640
Note: Values are order of magnitude estimates for planning purposes only. Actual vault volumes vary considerably depending on separator design features and pre-cast vault dimensions.	

6.1.2 Design Criteria

Details for a typical baffle oil/water separator are shown in Figure 36 (p. 158). **Other designs** and configurations of separator units and vaults are allowed, including above ground units. However, they must produce equivalent treatment results and treat equivalent flows as conventional units.

General Siting

1. Oil/water separators **must be installed off-line**, bypassing flows greater than the water quality design flow.
2. When a separator is required, it **shall precede other water quality treatment facilities** (except wetvaults). It may be positioned either upstream or downstream from flow control facilities, since there are both advantages and disadvantages with either placement.
3. In moderately pervious soils where **seasonal groundwater** may induce flotation, buoyancy tendencies shall be balanced by ballasting or other methods as appropriate.
4. Any **pumping devices** shall be installed downstream of the separator to prevent oil emulsification in stormwater.

Vault Structure — General

The following criteria apply to both baffle and coalescing plate separators:

1. Separator vaults shall be **watertight**. Where pipes enter and leave a vault below the water quality design water surface, they shall be sealed using a non-porous, non-shrinking grout.
2. Separator vaults shall have a **shutoff mechanism** on the outlet pipe to prevent oil discharges during maintenance and to provide emergency shut-off capability in case of a spill. A valve box and riser shall also be provided according to the design criteria for wetponds (see "Inlet and Outlet Criteria," Section 4.1.2, p. 77).

Vault Structure — Baffle Separators

In addition to the above general criteria, the following criteria apply specifically to baffle separators:

1. Baffle separators shall be divided into **three compartments**: a forebay, an oil separation cell, and an afterbay. The **forebay** is primarily to trap and collect sediments, encourage plug flow, and reduce turbulence. The **oil separation cell** traps and holds oil as it rises from the water column, and it serves as a secondary sediment collection area. The **afterbay** provides a relatively oil-free cell before the outlet, and it provides a secondary oil separation area and holds oil entrained by high flows.
2. The **length of the forebay** shall be approximately 1/3 to 1/2 of the length of the vault, *L*. In addition, the **surface area of the forebay** must be at least 20 square feet per 10,000 square feet of tributary impervious area draining to the separator.
3. A **removable flow-spreading baffle**, extending from the surface to a depth of up to 1/2 the vault depth (D) is recommended to spread flows.
4. The **removable bottom baffle** (sediment-retaining baffle) shall be a minimum of 24 inches (see Figure 36 (p. 158), and located at least 1 foot from the oil-retaining baffle. A

"window wall" baffle may be used, but the area of the window opening must be at least three times greater than the area of the inflow pipe.

5. A **removable oil retaining baffle** shall be provided and located approximately 1/4 *L* from the outlet wall or a minimum of 8 feet, whichever is greater (the 8-foot minimum is for maintenance purposes). The oil-retaining baffle shall extend from the elevation of the water surface to a depth of at least 50% of the design water depth. Various configurations are possible, but the baffle shall be designed to minimize turbulence and entrainment of sediment.
6. Baffles may be fixed rather than removable if additional entry ports and ladders are provided so that both sides of the baffle are accessible by maintenance crews.
7. Baffle separator vaults shall have a minimum **length-to-width ratio** of 5.
8. The **design water depth** (*D*) shall be no deeper than 8 feet unless approved by DCLU. Depths greater than 8 feet may be permitted on a case-by-case basis, taking into consideration the potential for depletion of oxygen in the water during the warm summer months.
9. Baffle separator vaults shall have a **design water depth-to-width** ratio of between 0.3 and 0.5.

Vault Structure — Coalescing Plate Separators

In addition to the above general criteria, the following criteria apply specifically to coalescing plate separators:

1. Coalescing plate separators shall be divided by baffles or berms into **three compartments**: a forebay, an oil separation cell which houses the plate pack, and an afterbay. The **forebay** controls turbulence and traps and collects debris. The **oil separation cell** captures and holds oil. The **afterbay** provides a relatively oil-free exit cell before the outlet.
2. The **length of the forebay** shall be a minimum of 1/3 the length of the vault, *L* (but 1/2 *L* is recommended). In addition, it is recommended that the **surface area of the forebay** be at least 20 square feet per 10,000 square feet of tributary impervious area draining to the separator. In lieu of an attached forebay, a separate grit chamber, sized to provide be at least 20 square feet per 10,000 square feet of tributary impervious area, may precede the oil/water separator.
3. An **oil-retaining baffle** shall be provided. For large units, a baffle position of 0.25*L* from the outlet wall is recommended. The oil-retaining baffle shall extend from the water surface to a depth of at least 50% of the design water depth. Various configurations are possible, but the baffle shall be designed to minimize turbulence and entrainment of sediment.
4. A bottom **sediment-retaining baffle** shall be provided upstream of the plate pack. The minimum height of the sludge-retaining baffle shall be 18 inches. Window walls may be used, but the window opening must be a minimum of three times greater than the area of the inflow pipe.
5. It is recommended that entire space between the sides of the plate pack and the vault wall be filled with a solid but light-weight removable material such as a **plastic or polyethylene foam** to reduce short-circuiting around the plate pack. Rubber flaps are not effective for this purpose.

6. The **separator plates** should meet the following requirements:
   a) Plates shall be inclined at 45° to 60° from the horizontal. This range of angles exceeds the angle of repose of many solids and therefore provides more effective droplet separation while minimizing the accumulation of solids on the individual plates.
   b) Plates shall have a minimum plate spacing of 1/2-inch and have corrugations.
   c) Plates shall be securely bundled in a plate pack so that they may be removed as a unit.
   d) The plate pack shall be a minimum of 6 inches from the vault bottom.
   e) There should be 1 foot of head space between the top of the plate pack and the bottom of the vault cover.

Inlet and Outlet

1. The **inlet shall be submerged**. A tee section may be used to submerge the incoming flow and must be at least 2 feet from the bottom of the tank and extend above the water quality design water surface.

   Intent: The submerged inlet is to dissipate energy of the incoming flow. The distance from the bottom is to minimize resuspension of settled sediments. Extending the tee to the surface allows air to escape the flow, thus reducing turbulence. Alternative inlet designs that accomplish these objectives are acceptable.

2. The **vault outlet pipe** shall be sized to pass the water quality design flow before overflow. The vault outlet pipe shall be back-sloped or have a tee extending 1 foot above and below the water quality design water surface to provide for secondary trapping of oils and floatables in the wetvault. *Note: The invert of the outlet pipe sets the* **water quality *design water surface*** *elevation.*

Material Requirements

1. All **metal parts shall be corrosion-resistant**. Zinc and galvanized materials are to be avoided when substitutes are available because of aquatic toxicity potential. Painting metal parts for corrosion resistance is not allowed due to lack of longevity.
2. **Vault baffles** shall be concrete, stainless steel, fiberglass reinforced plastic, or other acceptable material and shall be securely fastened to the vault.
3. **Gate valves**, if used, shall be designed for seating and unseating heads appropriate for the design conditions.
4. For coalescing plate separators, **plate packs** shall be made of fiberglass, stainless steel or polypropylene.

Access Requirements

Same as for **wetvaults** (see page 93) except for the following **modifications:**

1. Access to **each compartment** is required. If the length or width of any compartment exceeds 50 feet, an additional access point for each 50 feet is required.
2. Access points for the **forebay and afterbay** shall be positioned partially over the inlet or outlet tee to allow visual inspection as well as physical access to the bottom of the vault.
3. For **coalescing plate separators**, the following also apply:

a) Access to the **compartment containing the plate pack** shall be a removable panel or other access able to be opened wide enough to remove the entire coalescing plate bundle from the cell for cleaning or replacement. Doors or panels shall have stainless steel lifting eyes, and panels shall weigh no more than 5 tons per panel.

b) A **parking area or access pad** (25-foot by 15-foot minimum) shall be provided near the coalescing plate bundles to allow for their removal from the vault by a truck-mounted crane or backhoe, and to allow for extracting accumulated solids and oils from the vault using a vactor truck.

Access Roads

Same as for wetvaults (see page 94).

Recommended Design Features

1. A **gravity drain** for maintenance is recommended if grade allows. The drain invert should be at a depth equal to the depth of the oil retaining baffle. Deeper drains are encouraged where feasible.
2. The recommended design features for wetvaults should be applied.
3. If large amounts of oil are likely to be captured, a bleed-off pipe and separate waste oil tank can be located adjacent to the vault to channel separated oils into the tank. This improves the overall effectiveness of the facility, especially if maintenance is only annually. It also improves the quality of the waste oil recovered from the facility.

Construction Considerations

1. Construction of oil/water separators should follow and conform to the manufacturer's recommended construction procedures and installation instructions. Where the possibility of vault flotation exists, the vault shall be properly anchored in accordance with the manufacturer's recommendations or an engineer's design and recommendations.
2. Particular care must be taken when inserting coalescing plate packs in the vault so as not to damage or deform the plates.
3. Upon completion of installation, the oil/water separator shall be thoroughly cleaned and flushed prior to operating.

Maintenance Considerations

1. Oil/water separators must be cleaned regularly to ensure that accumulated oil does not escape from the separator. Separators should be cleaned by November 15 of each year to remove accumulation during the dry season. They must also be cleaned after spills of polluting substances such as oil, chemicals, or grease. Vaults must also be cleaned when inspection reveals any of the following conditions:

   a) Oil accumulation in the oil separation compartment equals or exceeds 1 inch, unless otherwise rated for greater oil accumulation depths recommended by the specific separator manufacturer.

   b) Sediment deposits in the bottom of the vaults equals or exceeds 6 inches in depth.

2. For the first several years, oil/water separators should be checked on a quarterly basis for proper functioning and to ensure that accumulations of oil, grease, and solids in the separator are at acceptable levels. Effluent from the vault shall also be observed for an oil sheen to ensure that oil concentrations are at acceptable levels and that expected

treatment is occurring. Separators should also be inspected after large storm events (about 2 inches in 24 hours).

3. Access to separators shall be maintained free of all obstructions, and units shall be readily accessible at all times for inspection and maintenance.
4. Maintenance personnel entering oil/water separator vaults should follow the state regulations pertaining to confined space entry, if applicable.

Baffle oil/water separators use vaults that have multiple cells separated by baffles extending down from the top of the vault (see Figure 36 on page 158 for schematic details). The baffles block oil flow out of the vault. Baffles are also commonly installed at the bottom of the vault to trap solids and sludge that accumulate over time. In many situations, simple floating or more sophisticated mechanical oil skimmers are installed to remove the oil once it has separated from the water.

Coalescing plate separators are typically manufactured units consisting of a baffled vault containing several inclined corrugated plates stacked and bundled together (see Figure 37 on page 159 for schematic details). The plates are equally spaced (typical plate spacing ranges from 1/4-inch to 1 inch) and are made of a variety of materials, the most common being fiberglass and polypropylene. Efficient separation results because the plates reduce the vertical distance oil droplets must rise in order to separate from the stormwater. Once they reach the plate, oil droplets form a film on the plate surface. The film builds up over time until it becomes thick enough to migrate upward under the influence of gravity along the inclined plate. When the film reaches the edge of the plate, oil is released as large droplets which rise rapidly to the surface, where the oil accumulates until the unit is maintained. Because the plate pack increases treatment effectiveness significantly, coalescing plate separators can achieve a specified treatment level with a smaller vault size than a simple baffle separator.

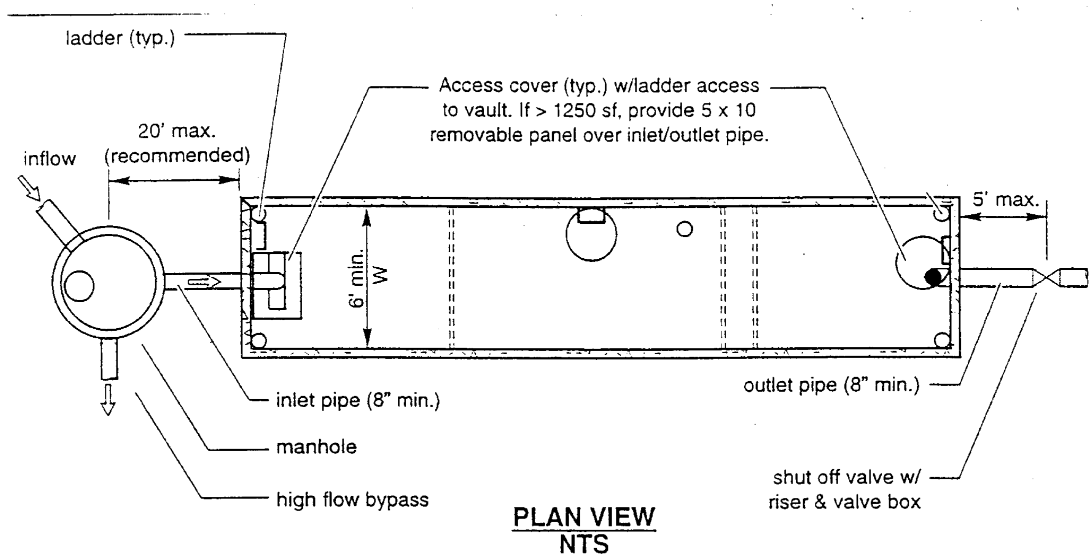
Oil/water separators are meant to treat stormwater runoff from more intensive land uses, such as high-use sites, and facilities that produce relatively high concentrations of oil and grease. Although baffle separators historically have been used to remove larger oil droplets (150 microns or larger), they can also be sized to remove smaller oil droplets.

Applications and Limitations

Oil/water separators are designed to remove free oil and are not generally effective in separating oil that has become either chemically or mechanically emulsified and dissolved in water. Therefore, it **is desirable for separators be installed upstream of facilities and conveyance structures that introduce turbulence and consequently promote emulsification**. Emulsification of oil can also result if surfactants or detergents are used to wash parking areas that drain to the separator. Detergents should not be used to clean parking areas unless the wash water is collected and disposed of properly (usually to the sanitary sewer).

Oil/water separators are **best located in areas where the tributary drainage area is nearly all impervious, and a fairly high load of petroleum hydrocarbons is likely to be generated**. Oil/water separators are not recommended for areas with very dilute concentrations of petroleum hydrocarbons since their performance is not effective at low concentrations. Excluding unpaved areas helps to minimize the amount of sediment entering the vault, reducing the need for maintenance. A unit that fails to function can release previously trapped oil to the downstream receiving water, both in release from the oily sediments and from entrainment of surface oils.

FIGURE 36. BAFFLE OIL/WATER SEPARATOR



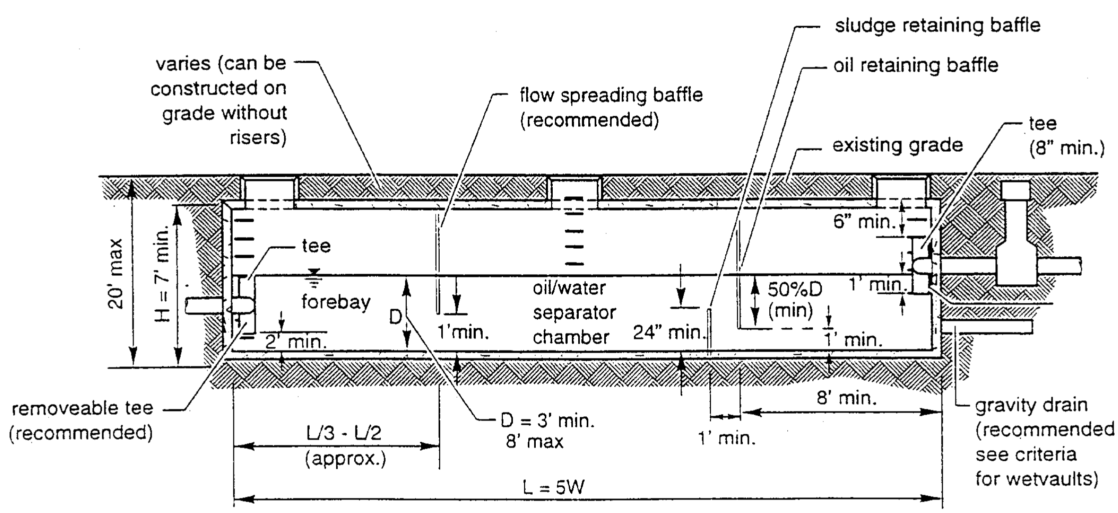
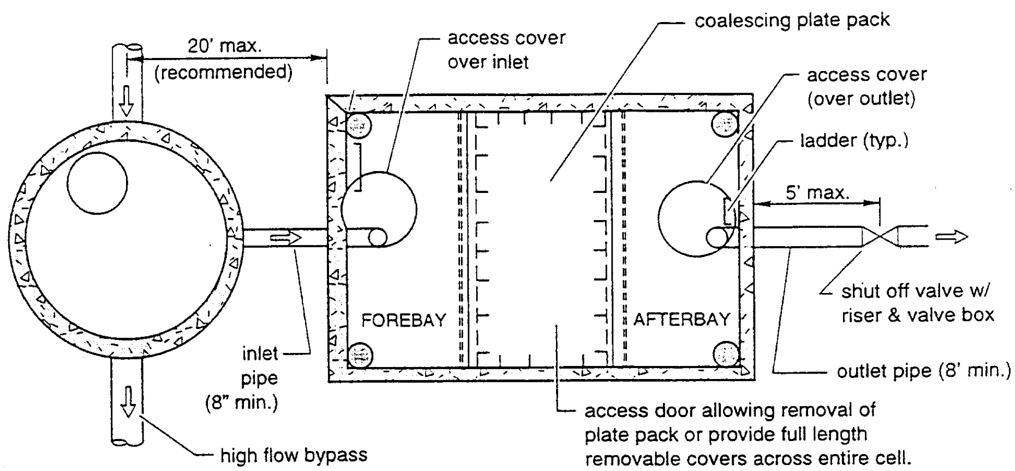
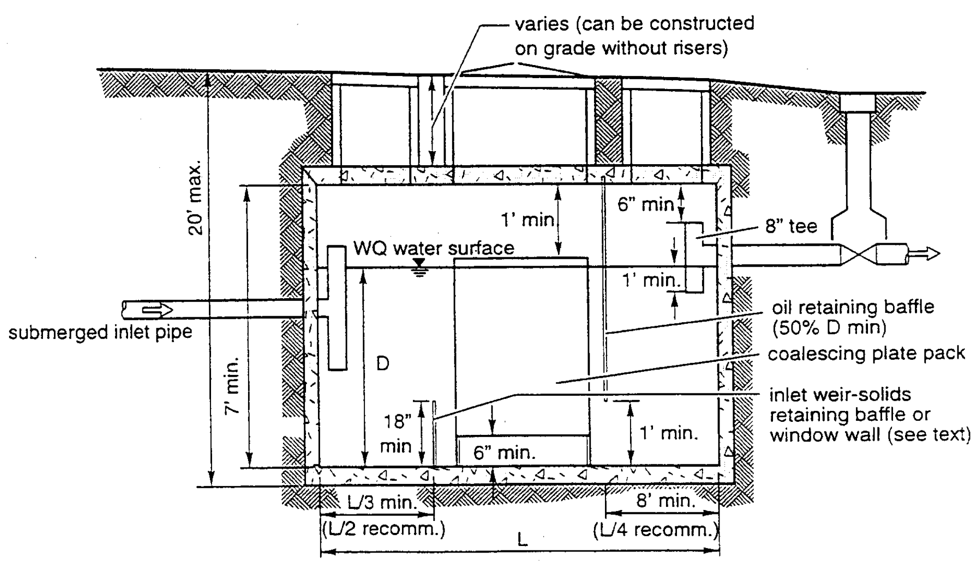


FIGURE 37. COALESCING PLATE OIL/WATER SEPARATOR



PLAN VIEW
NTS



SECTION VIEW
NTS

7 LANDSCAPE MANAGEMENT PLAN

Landscape management plans have the potential to significantly reduce the pollutant loading washing off managed green spaces. For this reason, landscape management plans that incorporate key pollution prevention elements and which are consistently implemented can be used in lieu of a basic stormwater quality treatment facility (see Section 1.1). This section contains guidelines for preparing a Landscape Management Plan. **Landscape management plans are submitted to DCLU with the permit application for approval.**

7.1 LANDSCAPE MANAGEMENT PLAN CONSIDERATIONS

Studies of pollutant transport have consistently shown that forested lands produce lower pollutant loads for solids, nutrients (e.g., nitrogen and phosphorus), and metals than do lands used for residential, industrial, or agricultural purposes. "Loading" refers to the total weight of a pollutant leaving a particular area or site. It is measured by determining both the concentration of a pollutant and the amount of flow leaving a site. Since the Puget Sound area was largely forested before settlement, lakes and streams in the area have developed biotic regimes in response to this low pollutant loading—clear, cool waters supporting salmon and other aquatic life. When the input of pollutants increases, lakes and streams often shift to a more biologically productive mode, often with a concomitant loss of clear water and a shift or even decline in fish species.

When forests are converted to cities, this increase in pollutant load needs to be managed in order to maintain the beneficial uses of lakes and streams. One way to manage pollutants is to treat stormwater before it enters a water body. Biofiltration swales, wet ponds, and sand filters, as well as other facilities, can be used to provide this treatment. Another approach to manage pollutant loads is to prevent the pollutants from entering stormwater in the first place.

Our best models on how to keep nutrients and other pollutants from entering stormwater are from the original, unaltered landscape—the forests. Forests have a soft, absorptive duff layer, as well as dense vegetative cover, especially near the ground surface. Nutrients are provided in the form of slow-release organic materials, or leaves, needles, and woody material. Rainfall runoff is greatly reduced from the levels seen in developed landscapes. These factors help to keep the total load of nutrients and sediments transported to receiving waters low.

7.2 ELEMENTS OF LANDSCAPE MANAGEMENT PLANS

Good planning, tailored to the specific conditions of the site, as well as good follow-through, are both essential in controlling the pollutants generated when forests are replaced with lawns, gardens, or other landscape features. This section will focus on planning. Follow-through, or implementation, will be discussed in the next section.

7.2.1 Plan Contents

A landscape management plan for any particular site works best if developed with the specific site characteristics in mind. Soil type, slope, exposure, depth of groundwater as well as the particular suite of plants chosen for the site all should help direct the specific make-up of the plan. However, there are some basic principles that all site should consider in order to be successful in controlling the export of soil or organic matter, fertilizers, and pesticides in stormwater runoff.

Landscape management plans should address each of the general principles give in Table 23, tailoring them to fit the specific site situation.

Each of the five basic principles is expanded upon in the following section. The recommendations discussed under each principle are intended as a framework for a variety of site situations, from individual homes to large parks and golf courses. Thus, not every landscape management plan may be able to apply each of the listed recommendations. In addition, landscapes are managed for different purposes, some more formal than others. It may be that some recommendations will not be appropriate for very formal sites and thus not adopted, in favor of other management practices that better fit the uses for which the site is intended. In the end, the extend to which a landscape management plan is successful depends on the ability of the practices chose to retain soil, fertilizers, and pesticides on the site and away from water resources throughout the entire year.

TABLE 23. BASIC PRINCIPLES TO REDUCE POLLUTANT TRANSPORT FROM LANDSCAPED AREAS

Principal	Title
#1	Minimize bare soil areas
#2	Reduce water demand
#3	Reduce extent of turf area—manage remaining turf for low-impact
#4	Choose plants with sustainability in mind
#5	Manage fertilizer and pesticide use wisely

Principle 1: Minimize Bare Soil Areas

Bare soil areas are one source of solids that can be mobilized and carried downstream by rainfall. Minimizing bare soil areas makes it less likely that solid particles will be dislodged by rainfall. Some pointers on how to manage landscapes to minimize bare soil are give below:

1. Establish dense plantings of pest-resistant groundcover t shade out weeds. Some easy-care recommendations are rock rose (*Cistus* sp.), snowberry (*Symphoricarpus alba*), salal (*Gaultheria shallon*), and kinnickinick (Arctosaphylos uva-ursi).
2. If bare soil areas are required, as in plant beds or ball diamonds, surround the bare area with an area of grass or groundcover to filter out solids that may be picked up by stormwater runoff.
   - The denser the grass or groundcover, the better it works to capture solids in runoff.
   - Try to make the filtering area as level as possible. Avoid low spots, where runoff can concentrate and create channels.
   - In general, filter areas should be about one-fourth as long (along the flow path) as the area contributing flow, assuming that slopes are gentle (i.e., less than 10 percent). For flat, level areas without dips, this length can be reduced.
3. Repair promptly bare patches in lawns or groundcovers that could contribute solids to stormwater runoff.

4. Don't place bark or loose mulch on slopes where it can be carried to storm drains.

Principle 2: Reduce Water Demand

Reducing the need for irrigation reduces the potential movement of pollutants, conserves water, and saves money.

1. Use drought tolerant or native vegetation.
2. Install underground irrigation systems timed to water at night or drip irrigation systems.
3. Increase the organic content of soils to improve water-retention capability.
4. Allow for longer water retention by terracing sloped areas.

Principle 3: Reduce Turf Area and Manage Remaining Turf for Low-Impact

Turf requires care to look good. In addition to mowing, turf areas typically require water, fertilizer, and weed disease control. However, some practices can reduce or minimize the amount of chemical controls needed.

1. Amend soil with organic matter to a depth of 8-12 inches before the lawn is established. Till the organic matter into the native soil.
2. Decide if all lawn areas need the same level of upkeep (let some areas have a less formal look if possible, and reduce fertilizer and pesticide use in those areas).
3. Rely on irrigation and lawn aeration as the primary tools to maintain healthy turf.
4. Remove thatch each year to increase water penetration to grass roots and reduce runoff.
5. Plant groundcovers rather than grass in shady areas. Turf grasses usually need at least partial sun to remain vigorous.

Principle 4: Choose Plants with Sustainability in Mind

Plants differ in their ability to cope with different soils, rainfall conditions, pest and diseases, and microclimates. Choosing resilient plant species, plants with adaptations for particular environments or creating optimal microenvironments are all techniques that can be used to create landscapes that require less intervention. Less watering and less need for pesticide and fertilizer application means less potential for pollutants to leave the site.

1. Choose disease resistant plants.
2. Choose drought-resistant groundcovers, shrubs, and trees in areas with poor soil or little shading.
3. Group plants in clusters with tree, shrub, and groundcover layers to create a better microenvironment and to supply organic matter back to the soil.
4. Include plants in the landscape that are important for beneficial insects such as parasitic wasps. If beneficial insects have nothing to sustain them, they won't stick around to control pests when you need them.
5. Use dense plantings or close spacing to shade out weeds rather than applying herbicides.
6. Use plants with fibrous roots on steeper slopes or erosion-prone areas. Some good choices include:
   - New Zealand flax (*Phormium penax*)
   - Ornamental grasses, lawn grasses

- Rock rose (*Cistu*s sp.)
- Salmonberry (*Rubus spectabilis*)—native
- Snowberry (*symphoricarpus alba*)—native

7. Use wetland plants in areas with seeps or a high water table.
8. Attend to installation details. Write enforceable planting specifications that include details such as soil preparation, plant spacing, plant condition and size, planting depth, transplant handling, and irrigation. Inspect the job during panting to prevent short cuts such as blowing the soil mixture around root balls rather than digging the roots into the amended native soils.

Principle 5: Manage Fertilizer and Pesticide Use Wisely

Many landscape plants and turf simply won't do well without fertilization and some amount of pest management. therefore, it's important for landscape management plans to address when and how these actions will be taken.

1. Keep plants healthy by building healthy soil using composted organic material. Healthy plants can better resist diseases and inspect pests.
2. Tailor fertilizer make-up to lawn needs. Adjust application rate and timing of fertilizer applications to avoid washoff in storm runoff.
3. Reduce the phosphorus concentration in fertilizers when possible by using a low phosphorus formulation or formulations containing only nitrogen or potassium. Added phosphorus is often not needed for healthy foliage growth, only for encouraging profuse blooms.
4. Use an integrated pest management approach to control pests. Keep current about non-chemical controls as a first defense against pests.
5. Encourage a diverse insect community in your landscape. Beneficial insects can help control pests, especially pests of trees and shrubs.
6. Target pesticide application to the specific pest of concern. Avoid pesticide "mixes" that target generic problems (such as weed and feed) unless you actually need each of the formulations for a current problem.
7. Only apply pesticides during the life-stage when the pest is vulnerable.
8. Use fungicides very sparingly—they disrupt the base of aquatic food webs. If you need to use fungicides, use formulations that have faster breakdown times. Consult a golf course management text for information on the attributes of various fungicides and other pesticides.
9. Tolerate some weeds.

7.2.2 Plan Implementation

A landscape management plan, no matter how good, will not reduce pollutants in runoff if it is not implemented. Implementation often means that the plan needs to be modified over time, since as plants grown, and as the cycle of pests change, the original plan may not fit the site. The following must be addressed before a landscape management plan can be approved by the City.

1. Identify who will be responsible for assuring that the management plan is carried out.

2. Identify how the applicant will assure that grounds crews or homeowners have the training and/or resources required to implement the plan and keep up to date on advances in landscape care practices and products.
3. Agree to keep records of fertilizer and pesticide application, including rate of application, area treated, and disposal or storage of residuals.
4. Agree to certify each year that the landscape management plan for the project in question has been carried out, and that needed amendments or updates have been made.
5. Provide the plan to City inspection personnel upon request.

8 ALTERNATIVE TREATMENT TECHNOLOGIES

The Stormwater, Grading and Drainage Control Code (SGDC Code) describes specific stormwater treatment facilities that must be installed to reduce pollution in stormwater from a developed site. The SGDC Code also allows **alternative treatment technologies** to be installed to meet the runoff treatment requirements provided certain criteria are met. These criteria include:

1. Treatment effectiveness monitoring is conducted;

2. Monitoring and maintenance records are reported to the Director of SPU at the end of each of the first three years following installation; and

3. The applicant demonstrates to the Director of SPU's satisfaction that the alternative will provide protection equivalent to the prescribed methods.

The monitoring requirement may be waived if sufficient research has been conducted to demonstrate to the Director of SPU's satisfaction that the proposed alternative technology offers protection equivalent to that afforded by the prescribed stormwater treatment facilities.

8.1 GENERAL POLICY FOR ALTERNATIVE TECHNOLOGIES

The list of acceptable stormwater treatment facilities contained in the SGDC Code includes: infiltration, wetponds, stormwater wetlands, biofiltration swales, filter strips, wet vaults, and media filters. Additional measures required for high use sites are: coalescing plate/ oil water separators, media filters, and API oil/water separators. However, establishing a list of accepted technologies is not meant to foreclose on other options that may prove as effective, or more effective, and the SGDC Code states that alternative technologies *may* be permitted. Example of alternative technologies that may be accepted can include both structural facilities, such as proprietary confined space systems or catch basin inserts, and non-structural actions, such as increased maintenance frequencies or enhanced pollution prevention activities. As a general policy, alternative technologies may be permitted provided one of the following conditions exist:

1. There is existing data and information on the performance of the alternative technology sufficient to demonstrate to the Director of SPU's satisfaction that the proposed alternative technology offers equivalent protection to that provided by one of the listed treatment facilities. In this case, additional monitoring will not be required and the technology should be permitted as an alternative to the prescribe treatment facility or facilities.
2. There is a compelling interest on the part of SPU to evaluate the performance of the alternative technology and there is a reasonable expectation that the technology will provide an equivalent level of protection. In this case, an agreement is made between SPU and the applicant who is proposing the alternative technology. This agreement will require that the applicant collect the information and conduct monitoring necessary to evaluate the performance of the alternative technology, and will describe any subsequent requirements following the evaluation period.

Determining **equivalent level of protection** by the Director of SPU involves both an objective and subjective evaluation of the proposed technology's ability to remove a range of pollutants under varying flow rates and inflow pollutant concentrations.

A proposed alternative technology may be rejected from consideration for any one of the following reasons:

1. There is existing data and information on the performance of the alternative technology indicating that the proposed alternative technology *will not* provide equivalent protection to that provided by one of the prescribed treatment facilities.
2. There is *no* compelling interest on the part of SPU to evaluate the performance of the proposed alternative technology. This may be owing to one of the following factors:
    a. Monitoring is already in progress on the same or similar type of alternative technology, and expending additional resources to duplicate the monitoring efforts cannot be justified; or
    b. Other considerations beyond equivalent level of protection, such as on-site conditions, system reliability, or maintenance and operational requirements, limit the interest in expending resources necessary to evaluate the effectiveness of the proposed alternative.

8.2 GENERAL PROCEDURE FOR ALTERNATIVE TECHNOLOGIES

In general, the following steps will be followed when evaluating an alternative technology:

1. The applicant will gather sufficient information necessary for the Director of SPU to evaluate:
    a. The expected level of protection the technology will provided, and
    b. The nature of the alternative technology and whether there is a compelling interest to evaluate the performance of the technology.

    The information to be submitted to SPU before an alternative technology can be permitted is shown in Table 24. This purpose of this preliminary information is to provide reviewers the details necessary to determine if the proposed alternative technology is likely to provide equivalent level of protection *and* to determine if there is a compelling interest in evaluating the performance of the alternative technology. The information elements listed in Table 24 are divided into two categories, either required or desired, and includes information need for both structural and non-structural alternative technology proposals.
2. The Director of SPU will make a determination regarding whether the alternative technology should be allowed in place of the treatment facility prescribed in the SGDC Code.
    a. If the alternative technology is rejected, the Director of SPU will inform the applicant of the reason(s) for rejection and the applicant may choose to either make any necessary changes in the proposal and resubmit the proposal or install one of the treatment facilities prescribed in the SGDC Code.
    b. If the proposed technology is accepted as an alternative based on existing data and information, then the Director of SPU will inform the applicant that the

technology should be permitted as an alternative to the prescribe treatment facility or facilities. The applicant may then proceed with the project, consistent with other City codes and requirements. In this case, additional monitoring will not be required.

c. If the proposed technology is may be acceptable as an alternative and there is compelling interest to evaluate the performance, then the Director of SPU will assign a Project Manager to work with the applicant throughout the evaluation period.

3. The SPU Project Manager will work with the applicant to develop a data collection protocol and establish any other actions and record keeping requirements necessary to fully evaluate the proposed alternative technology.

4. Prior to installing the alternative treatment facility (in the case of a structural alternative technology) or commencing the activity (in the case of a non-structural alternative technology), the SPU Project Manager will proposed a schedule and budget covering the first three years of the evaluation period. The applicant may either:

    a. Accept the proposal and enter into an agreement with SPU to conduct the evaluation, or

    b. Reject the proposal and install one of the treatment facilities prescribed in the SGDC Code.

5. During the evaluation period, the applicant will report monitoring and maintenance records to the Director of SPU at the end of each of the first three years following installation/commencement, and provide any other information and updates as required by the agreement.

6. At the end of the evaluation period, the applicant must demonstrate to the Director of SPU's satisfaction that the alternative will provide protection equivalent to the prescribed methods.

    a. If the alternative provides equivalent protection, the applicant must agree to maintain the alternative treatment facility (in the case of a structural alternative technology) or continue conducting the activity (in the case of a non-structural alternative technology) for the life of the site.

    b. If the alternative does not provide equivalent protection, the applicant must take additional steps, as prescribed in the agreement with the Director of SPU, which may include:

        - Taking additional steps to enhance the performance of the alternative; and/or

        - Installing additional facilities as necessary to provide equivalent protection; and/or

        - Completing other actions, as prescribed in the agreement between SPU and the applicant, necessary to provide equivalent protection.

7. The Director of SPU may, during and/or after completion of the evaluation period, collect additional data, at the City's expense, to further evaluate the performance of the alternative technology.

TABLE 24. PRELIMINARY DATA AND INFORMATION ELEMENTS FOR CONSIDERING AN ALTERNATIVE TECHNOLOGY		
PART A. SITE INFORMATION (ALL PROPOSED TECHNOLOGIES)		
Data Element	**Description**	**Required/Desired**
BMP Test Site Name	Name that the site is known by locally (e.g., Chandler Family Bakery, Elswick Creek, Schmoyer Chocolate Stop).	Required
Address of Test Site	Street address and Zip Code	Required
Primary Point of Contact	Name, address, phone number(s) of individual(s) involved in proposing the alternative technology.	Required
Drainage Area	Total catchment area contributing runoff to the proposed alternative technology. If the proposed alternative technology is non-structural, the reported value should be the total area contributing runoff on the site before it enters the storm drain system.	Required
Land Use	Types of land use on the site, to the include the following categories, as applicable, reported as either area or fractional percentage of total area: 1. % Light Industrial 2. % Heavy Industrial 3. %Multi-family Residential 4. % Single-family Residential 5. % Office Commercial 6. % Retail 7. % Restaurant/Fast Food 8. % Automotive Services 9. % Roadway 10. Other type s of land use	Required
Land Surface	Types of land surface use on the site, to include the following categories, as applicable, reported as either area or fractional percentage total area: 1. Rooftop 2. Concrete or Asphalt Parking (% long-term and/or short term) 3. Walkway/Sidewalk 4. Patio, Decking 5. Gravel 6. Packed earthen material or other surfaces impeding natural infiltration of urban runoff. 7. Plantings 8. Lawn 9. Other landscaping features (describe) 10. Any other land use features that may affect the amount or quality of stormwater runoff on the site.	Required
Average Slope	Average unitless slope (e.g., ft/ft) of the area draining to the alternative technology.	Required
Estimated Flow Rate	An estimate of the flow rate entering the alternative technology, based on the 6-month, 24-hour water quality design storm.	Required
Other Site Information	Any other information pertinent to describing the site and its characteristics that have a bearing on the runoff quality or quantity	Desired

TABLE 24. PRELIMINARY DATA AND INFORMATION ELEMENTS FOR CONSIDERING AN ALTERNATIVE TECHNOLOGY (CONTINUED)

PART B. ALTERNATIVE TECHNOLOGY INFORMATION – NON-STRUCTURAL BMPS

Data Element	Description	Required/Desired
Non-structural BMP Type	Non-structural BMPs are generally described as a preventative action to protect receiving water quality that does not require construction. BMP types include: 1. Education 2. Maintenance Practices 3. Source Control	Required
Proposed Activities	A description of the proposed activities to be conducted.	Required
Estimated Costs	Provide estimates of the initial (i.e., start-up) costs, and annual recurring costs once the initial program has been developed, over at least a three-year period.	Required
Justification	Provide reasons why the proposed alternative technology is expected to provide an equivalent level protection of the structural treatment facilities prescribed in the SGDC Code.	Required
Other expected Benefits and Outcomes	A qualitative and quantitative description of the anticipated benefits to be attained by using the proposed alternative technology.	Required
Proposed Measurements	The measurements proposed to evaluate the effectiveness of the proposed alternative technology.	Required
Other Comments	Any other information pertinent to describing the proposed alternative technology useful for evaluating the value of expending resources to evaluate its effectiveness.	Desired

TABLE 24. PRELIMINARY DATA AND INFORMATION ELEMENTS FOR CONSIDERING AN ALTERNATIVE TECHNOLOGY (CONTINUED)		
PART C. ALTERNATIVE TECHNOLOGY INFORMATION – STRUCTURAL TREATMENT FACILITY		
Data Element	**Description**	**Required/Desired**
Name of Treatment Facility	Type of treatment facility, by brand name (e.g., Binns Technologies, Berentsen Filters) or general treatment category (enhanced infiltration)	Required
Proposed Activities	A description of the proposed activities to be conducted.	Required
Estimated Costs	Provide estimates of the initial (i.e., start-up) costs, and annual recurring costs once the initial program has been developed, over at least a three-year period.	Required
Justification	Provide reasons why the proposed alternative technology is expected to provide an equivalent level protection of the structural treatment facilities prescribed in the SGDC Code.	Required
Other expected Benefits and Outcomes	A qualitative and quantitative description of the anticipated benefits to be attained by using the proposed alternative technology.	Required
Proposed Measurements	The measurements proposed to evaluate the effectiveness of the proposed alternative technology.	Required
Other Comments	Any other information pertinent to describing the proposed alternative technology useful for evaluating the value of expending resources to evaluate its effectiveness.	Desired

APPENDIX A

HYDROLOGIC ANALYSIS

City of Seattle
Stormwater Treatment Technical
Requirements Manual

Effective January 1, 2001

APPENDIX A - HYDROLOGIC ANALYSIS[1]

A1 INTRODUCTION

The broad definition of hydrology is "the science which studies the source, properties, distribution, and laws of water as it moves through its closed cycle on the earth (the hydrologic cycle)." As applied in this manual, however, the term "hydrologic analysis" addresses and quantifies only a small portion of this cycle. That portion is the relatively short-term movement of water over the land resulting directly from precipitation and called surface water or stormwater runoff. Localized and long-term ground water movement must also be of concern, but generally only as they affect or relate to the movement of water on or near the surface, such as stream base flow or infiltration systems.

A2 DISCUSSION OF HYDROLOGIC ANALYSIS METHODS USED FOR DESIGNING BMPS

This discussion will focus on the use of the Santa Barbara Urban Hydrograph method (hereafter "SBUH"). To meet the treatment requirements of the City of Seattle, the 6-month, 24-hour water quality design storm must be treated.

Before using the SBUH method, it is important to understand the different concerns for **runoff treatment design storms** as opposed to the **flow control design storms**. The *runoff treatment design* storm is the 6-month, 24-hour event and the major concern with using SBUH is the need to accurately model inflow hydrographs for infiltration, filtration, and detention-type BMPs. Recall that the 6-month, 24-hour storm volume is equal to 64 percent of the volume of the 2-year, 24-hour storm event. No correction factor to the BMP volume is necessary for the runoff treatment storm. The situation with flow control storms (i.e., the 2-, 25-, and 100-year events) is quite different. For these events, BMPs are sized based on a comparison of the *existing condition* hydrograph with the *developed condition* hydrograph (for runoff treatment only the *developed condition is* modeled). There are two primary concerns with the use of SBUH when designing flow control BMPs: The first is how it estimates peak flow rates for pervious areas. The second concern is the use of a 24-hour duration storm, which is too short a duration in the Puget Sound basin for larger storms.

A summary of the concerns with SBUH is in order. While SBUH gives acceptable estimates of total runoff volumes, it tends to overestimate peak flow rates from pervious areas because it cannot adequately model subsurface flow (which is a dominant flow regime for pre-development conditions in the Puget Sound basin). One reason SBUH overestimates the peak flow rate for pervious areas is because the actual time of concentration is typically greater than what is assumed. Better flow estimates could be made if a longer time of concentration was used. This would change both the peak flow rate (i.e., it would be lower) and the shape of the hydrograph (i.e., peak occurs somewhat later) such that the hydrograph would better reflect actual conditions. Note that it is *not* necessary to make corrections to the curve number ("CN") for modeling runoff from pervious areas when using SBUH.

The other major weakness of the current use of SBUH is that it is used to model a 24-hour storm event, which is too short to model larger storms in the Puget Sound basin. The use of a 7-day storm is a more correct choice for Puget Sound, in conjunction with the use of a continuous simulation model. Note that the use of the 7-day duration storm would apply *only* to flow control BMPs and not to runoff treatment BMPs, as the 24-hour duration event is the correct one for runoff treatment purposes.

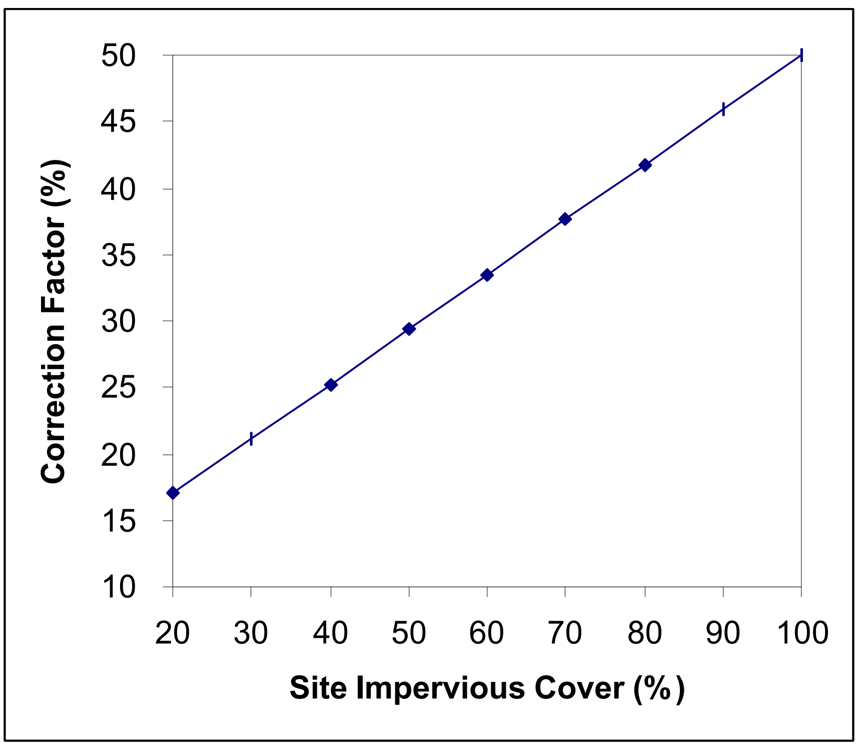
[1] Adapted from *Stormwater Management Manual for the Puget Sound Basin*, 1992. Washington State Department of Ecology, Olympia.

When designing a runoff treatment BMP, the primary concern with using SBUH is modeling of the inflow hydrograph to the BMP. SBUH tends to underestimate the time of concentration, thus the peak flow rate occurs too early. This can create problems for detention-type BMPs, such as pre-settling basins and dry vaults, because these BMPs are designed to achieve a 24-hour *residence time.* Calculation of the residence time is sensitive to the shape of the inflow hydrograph. The inflow hydrograph is also of fundamental importance when designing an infiltration or filtration BMP as these BMPs are sized based on a routing of the inflow hydrograph through the BMP. The best solution at this time is to try to account for subsurface flow when estimating the time of concentration. For sites with low impervious cover, this will increase the time of concentration, thus reducing the peak flow rate and shifting the peak rate to a somewhat later time. Note that for BMPs which maintain "permanent pools" (e.g., wet ponds) then none of the above concerns apply since the permanent pool volume is adequately predicted by SBUH.

When designing flow control BMPs, it will be necessary to apply a correction factor to the design volume of the BMP when using SBUH to model 24-hour storm events. It is recommended that correction factors of 20 percent and 50 percent apply to residential sites and commercial sites, respectively. Figure A1 is provided, which graphically illustrates the correction factor based on site impervious cover. This correction factor is to be applied to the volume of the BMP without changing its depth or the design of the outlet structure, thus an increase in surface area will result

Figure A1. Volume Correction Factor to be Applied to Streambank Erosion Control BMPs

(Based on Site Impervious Cover)



A3 HYDROGRAPH METHOD

Hydrograph analysis utilizes the standard plot of runoff flow versus time for a given design storm, thereby allowing the key characteristics of runoff such as volume, and phasing to be considered in the design of drainage facilities.

The physical characteristics of the site and the design storm determine the magnitude, volume, and duration of the runoff hydrograph. Other factors such as the conveyance characteristics of channel or pipe, merging tributary flows, branching of channels, and flooding of lowlands can alter the shape and magnitude of the hydrograph. In the following sections, the key elements of hydrograph analysis are presented, namely:

- Design storm hyetograph
- Runoff parameters
- Hydrograph synthesis

A3.1 Design Storm Hyetograph

All storm event hydrograph methods require the input of a rainfall distribution or design storm hyetograph. The design storm hyetograph is essentially a plot of rainfall depth versus time for a given design storm frequency and duration. It is usually presented as a dimensionless plot of unit rainfall depth (increment rainfall depth for each time interval divided by the total rainfall depth) versus time.

The hyetographs provided in this section is to be used for all hydrograph analysis. The design storm hyetograph *for sizing treatment facilities* using the SBUH method uses the standard *SCS Type 1A* storm event, where 5.40% of the rainfall occurs at the peak. See Table A1 and Figure A2. In the City of Seattle, the design storm hyetograph *for sizing flow control facilities* using the SBUH method is based on a SCS Type 1A storm event hyetograph that has been modified so that 9.92% of the rainfall occurs during the ten-minute period at the peak of the storm event. See Table A2 and Figure A3. This modified SCS Type 1A hyetograph causes a higher design flow to be computed than would be computed using the standard SCS Type 1A hyetograph. This will result in larger stormwater flow control facilities being designed, which is appropriate for flow control aplication, because it helps account for the likelihood of sequential storm events.

The design storm hyetograph is constructed by multiplying the dimensionless *hyetograph times* the rainfall depth (in inches) for the design storm. For the City of Seattle, the following values should be used:

6-month, 24-hour storm	1.080 inches
2-year, 24-hour storm	1.680 inches
25-year, 24-hour storm	3.125 inches
100-year, 24-hour storm	3.840 inches

Table A1. 24-hour SCS Type 1A Design Storm Hyetograph Values for Sizing Treatment Facilities

Time from beginning of Storm	Percent Rainfall	Cumulative Rainfall	Time from beginning of Storm	Percent Rainfall	Cumulative Rainfall	Time from beginning of Storm	Percent Rainfall	Cumulative Rainfall
0	0.00%	0.00%	490	1.80%	46.34%	980	0.50%	81.40%
10	0.40%	0.40%	500	1.34%	47.68%	990	0.50%	81.90%
20	0.40%	0.80%	510	1.34%	49.02%	1000	0.50%	82.40%
30	0.40%	1.20%	520	1.34%	50.36%	1010	0.40%	82.80%
40	0.40%	1.60%	530	0.88%	51.24%	1020	0.40%	83.20%
50	0.40%	2.00%	540	0.88%	52.12%	1030	0.40%	83.60%
60	0.40%	2.40%	550	0.88%	53.00%	1040	0.40%	84.00%
70	0.40%	2.80%	560	0.88%	53.88%	1050	0.40%	84.40%
80	0.40%	3.20%	570	0.88%	54.76%	1060	0.40%	84.80%
90	0.40%	3.60%	580	0.88%	55.64%	1070	0.40%	85.20%
100	0.40%	4.00%	590	0.88%	56.52%	1080	0.40%	85.60%
110	0.50%	4.50%	600	0.88%	57.40%	1090	0.40%	86.00%
120	0.50%	5.00%	610	0.88%	58.28%	1100	0.40%	86.40%
130	0.50%	5.50%	620	0.88%	59.16%	1110	0.40%	86.80%
140	0.50%	6.00%	630	0.88%	60.04%	1120	0.40%	87.20%
150	0.50%	6.50%	640	0.88%	60.92%	1130	0.40%	87.60%
160	0.50%	7.00%	650	0.72%	61.64%	1140	0.40%	88.00%
170	0.60%	7.60%	660	0.72%	62.36%	1150	0.40%	88.40%
180	0.60%	8.20%	670	0.72%	63.08%	1160	0.40%	88.80%
190	0.60%	8.80%	680	0.72%	63.80%	1170	0.40%	89.20%
200	0.60%	9.40%	690	0.72%	64.52%	1180	0.40%	89.60%
210	0.60%	10.00%	700	0.72%	65.24%	1190	0.40%	90.00%
220	0.60%	10.60%	710	0.72%	65.96%	1200	0.40%	90.40%
230	0.70%	11.30%	720	0.72%	66.68%	1210	0.40%	90.80%
240	0.70%	12.00%	730	0.72%	67.40%	1220	0.40%	91.20%
250	0.70%	12.70%	740	0.72%	68.12%	1230	0.40%	91.60%
260	0.70%	13.40%	750	0.72%	68.84%	1240	0.40%	92.00%
270	0.70%	14.10%	760	0.72%	69.56%	1250	0.40%	92.40%
280	0.70%	14.80%	770	0.57%	70.13%	1260	0.40%	92.80%
290	0.82%	15.62%	780	0.57%	70.70%	1270	0.40%	93.20%
300	0.82%	16.44%	790	0.57%	71.27%	1280	0.40%	93.60%
310	0.82%	17.26%	800	0.57%	71.84%	1290	0.40%	94.00%
320	0.82%	18.08%	810	0.57%	72.41%	1300	0.40%	94.40%
330	0.82%	18.90%	820	0.57%	72.98%	1310	0.40%	94.80%
340	0.82%	19.72%	830	0.57%	73.55%	1320	0.40%	95.20%
350	0.95%	20.67%	840	0.57%	74.12%	1330	0.40%	95.60%
360	0.95%	21.62%	850	0.57%	74.69%	1340	0.40%	96.00%
370	0.95%	22.57%	860	0.57%	75.26%	1350	0.40%	96.40%
380	0.95%	23.52%	870	0.57%	75.83%	1360	0.40%	96.80%
390	0.95%	24.47%	880	0.57%	76.40%	1370	0.40%	97.20%
400	0.95%	25.42%	890	0.50%	76.90%	1380	0.40%	97.60%
410	1.34%	26.76%	900	0.50%	77.40%	1390	0.40%	98.00%
420	1.34%	28.10%	910	0.50%	77.90%	1400	0.40%	98.40%
430	1.34%	29.44%	920	0.50%	78.40%	1410	0.40%	98.80%
440	1.80%	31.24%	930	0.50%	78.90%	1420	0.40%	99.20%
450	1.80%	33.04%	940	0.50%	79.40%	1430	0.40%	99.60%
460	3.40%	36.44%	950	0.50%	79.90%	1440	0.40%	100.00%
470	5.40%	41.84%	960	0.50%	80.40%			
480	2.70%	44.54%	970	0.50%	80.90%			

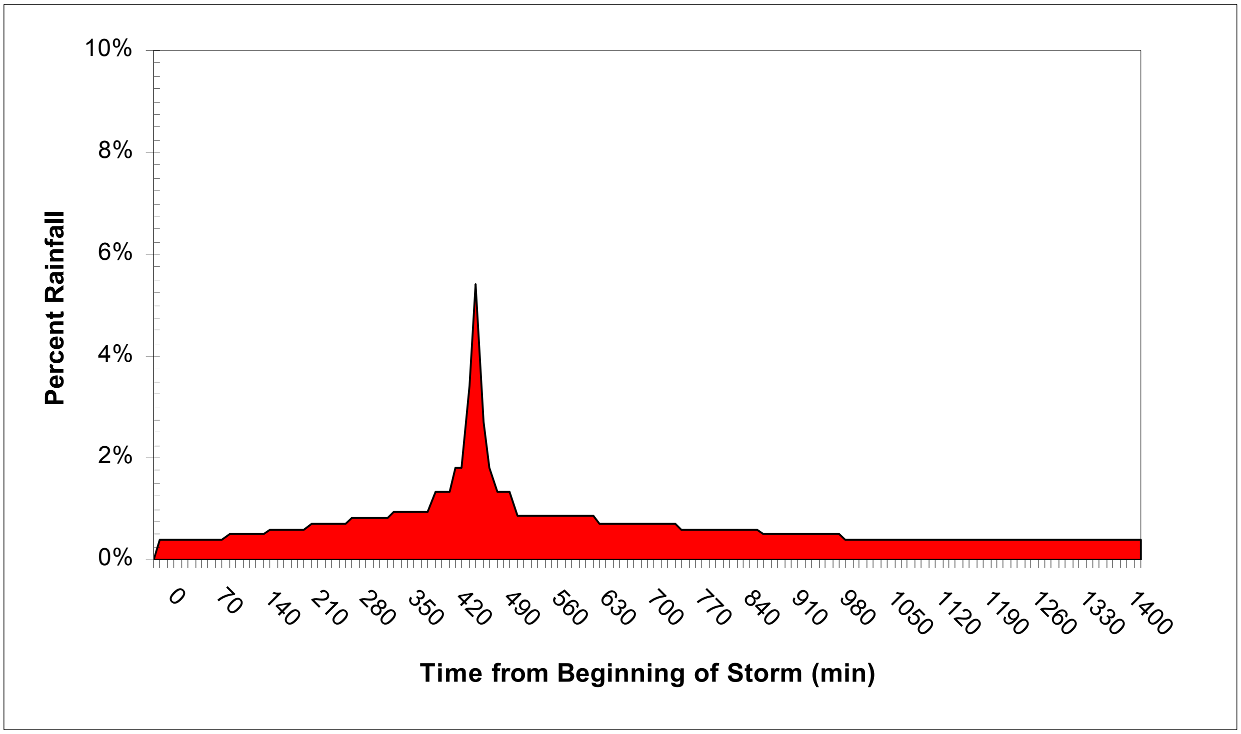


Figure A2. 24-hour SCS Type 1A Design Storm Hyetograph Values for Sizing Treatment Facilities

Table A2. 24-hour SEATTLE Design Storm Hyetograph Values for Sizing Flow Control Facilities

Time from beginning of Storm	Percent Rainfall	Cumulative Rainfall	Time from beginning of Storm	Percent Rainfall	Cumulative Rainfall	Time from beginning of Storm	Percent Rainfall	Cumulative Rainfall
0	0.00%	0.00%	490	1.80%	51.59%	980	0.50%	86.65%
10	0.40%	0.40%	500	1.34%	52.93%	990	0.50%	87.15%
20	0.40%	0.80%	510	1.34%	54.27%	1000	0.50%	87.65%
30	0.40%	1.20%	520	1.34%	55.61%	1010	0.40%	88.05%
40	0.40%	1.60%	530	0.88%	56.49%	1020	0.40%	88.45%
50	0.40%	2.00%	540	0.88%	57.37%	1030	0.40%	88.85%
60	0.40%	2.40%	550	0.88%	58.25%	1040	0.40%	89.25%
70	0.40%	2.80%	560	0.88%	59.13%	1050	0.40%	89.65%
80	0.40%	3.20%	570	0.88%	60.01%	1060	0.40%	90.05%
90	0.40%	3.60%	580	0.88%	60.89%	1070	0.40%	90.45%
100	0.40%	4.00%	590	0.88%	61.77%	1080	0.40%	90.85%
110	0.50%	4.50%	600	0.88%	62.65%	1090	0.40%	91.25%
120	0.50%	5.00%	610	0.88%	63.53%	1100	0.40%	91.65%
130	0.50%	5.50%	620	0.88%	64.41%	1110	0.40%	92.05%
140	0.50%	6.00%	630	0.88%	65.29%	1120	0.40%	92.45%
150	0.50%	6.50%	640	0.88%	66.17%	1130	0.40%	92.85%
160	0.50%	7.00%	650	0.72%	66.89%	1140	0.40%	93.25%
170	0.60%	7.60%	660	0.72%	67.61%	1150	0.40%	93.65%
180	0.60%	8.20%	670	0.72%	68.33%	1160	0.40%	94.05%
190	0.60%	8.80%	680	0.72%	69.05%	1170	0.40%	94.45%
200	0.60%	9.40%	690	0.72%	69.77%	1180	0.40%	94.85%
210	0.60%	10.00%	700	0.72%	70.49%	1190	0.40%	95.25%
220	0.60%	10.60%	710	0.72%	71.21%	1200	0.40%	95.65%
230	0.70%	11.30%	720	0.72%	71.93%	1210	0.32%	95.97%
240	0.70%	12.00%	730	0.72%	72.65%	1220	0.32%	96.29%
250	0.70%	12.70%	740	0.72%	73.37%	1230	0.32%	96.61%
260	0.70%	13.40%	750	0.72%	74.09%	1240	0.32%	96.93%
270	0.70%	14.10%	760	0.72%	74.81%	1250	0.32%	97.25%
280	0.70%	14.80%	770	0.57%	75.38%	1260	0.32%	97.57%
290	0.82%	15.62%	780	0.57%	75.95%	1270	0.32%	97.89%
300	0.82%	16.44%	790	0.57%	76.52%	1280	0.32%	98.21%
310	0.82%	17.26%	800	0.57%	77.09%	1290	0.16%	98.37%
320	0.82%	18.08%	810	0.57%	77.66%	1300	0.16%	98.53%
330	0.82%	18.90%	820	0.57%	78.23%	1310	0.16%	98.69%
340	0.82%	19.72%	830	0.57%	78.80%	1320	0.16%	98.85%
350	0.95%	20.67%	840	0.57%	79.37%	1330	0.16%	99.01%
360	0.95%	21.62%	850	0.57%	79.94%	1340	0.16%	99.17%
370	0.95%	22.57%	860	0.57%	80.51%	1350	0.16%	99.33%
380	0.95%	23.52%	870	0.57%	81.08%	1360	0.16%	99.49%
390	0.95%	24.47%	880	0.57%	81.65%	1370	0.16%	99.65%
400	0.95%	25.42%	890	0.50%	82.15%	1380	0.16%	99.81%
410	1.33%	26.75%	900	0.50%	82.65%	1390	0.03%	99.84%
420	1.33%	28.08%	910	0.50%	83.15%	1400	0.03%	99.87%
430	1.33%	29.41%	920	0.50%	83.65%	1410	0.03%	99.90%
440	1.80%	31.21%	930	0.50%	84.15%	1420	0.03%	99.93%
450	1.80%	33.01%	940	0.50%	84.65%	1430	0.03%	99.96%
460	4.16%	37.17%	950	0.50%	85.15%	1440	0.03%	99.99%
470	9.92%	47.09%	960	0.50%	85.65%			
480	2.70%	49.79%	970	0.50%	86.15%			

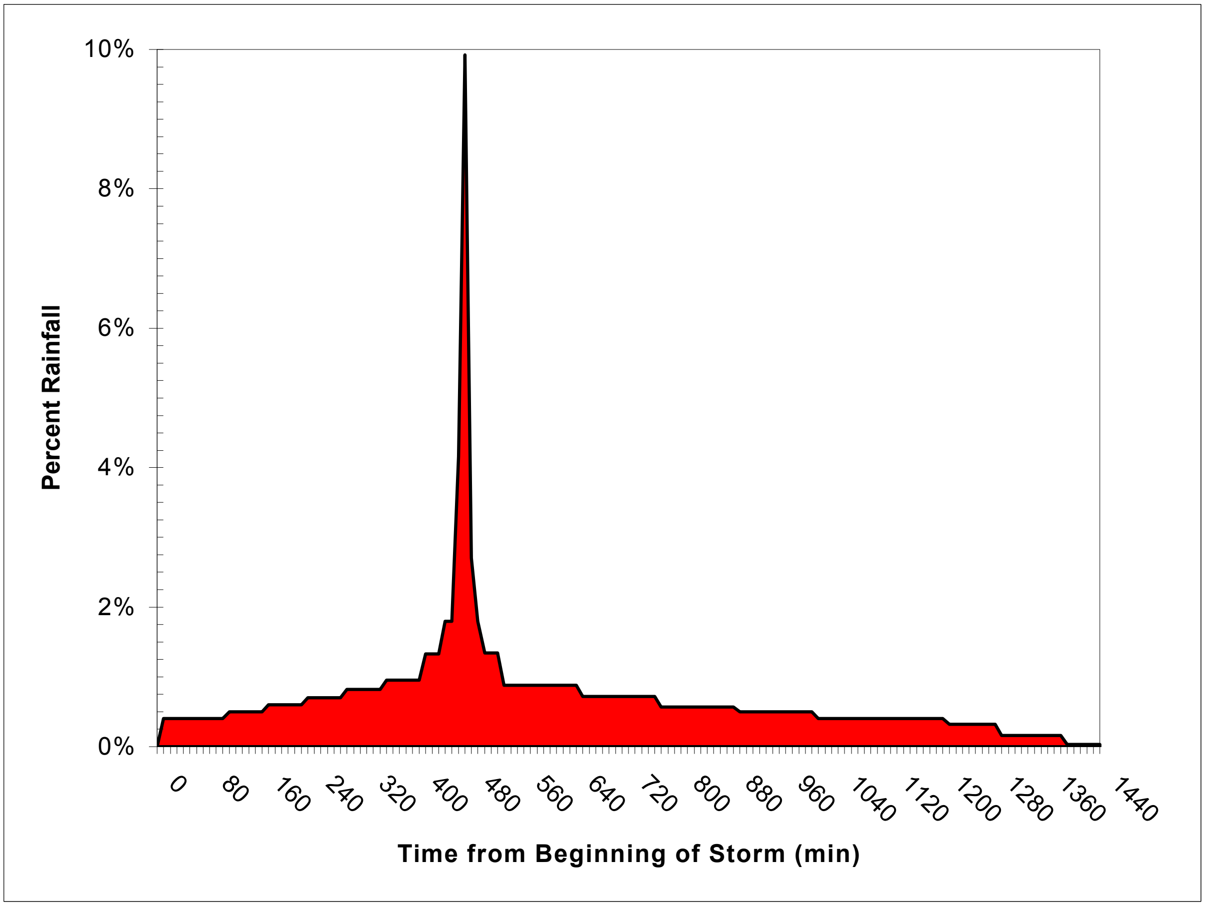


Figure A3. 24-hour SEATTLE Design Storm Hyetograph Values for Sizing Flow Control Facilities

A3.2 Runoff Parameters

All storm event hydrograph methods require input of parameters which describe physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. This section describes the three key parameters (area, curve number, and time of concentration) used to develop the hydrograph using the method of hydrograph synthesis discussed in Section A3.3.

3.2.1 Area

The proper selection of homogeneous basin areas is required to obtain the highest degree of accuracy in hydrograph analysis. Significant differences in land use within a given drainage basin must be addressed by dividing the basin area into subbasin areas of similar land use and/or runoff characteristics. For example, a drainage basin consisting of a concentrated residential area and a large forested area should be divided into two subbasin areas accordingly. Hydrographs should then be computed for each subbasin area and summed to form the total runoff hydrograph for the basin. To further enhance the accuracy of hydrograph analysis, all pervious and impervious areas within a given basin or subbasin shall be analyzed separately. This may be done by either computing separate hydrographs for each area and combining them to form the total runoff hydrograph or by computing the precipitation excess for each area and combining the two to obtain the total precipitation excess, which is then used to develop the runoff hydrograph. This procedure is explained further in Section A3.3 "Hydrograph Synthesis." By analyzing pervious and impervious areas separately the errors associated with averaging these areas are avoided and the true shape of the runoff hydrograph is better approximated.

3.2.2 Curve Number

The Soil Conservation Service (SCS) has, for many years, conducted studies into the runoff characteristics of various land types. After gathering and analyzing extensive data, SCS has developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage, and runoff. The relationships have been characterized by a single runoff coefficient called a "curve number." The National Engineering Handbook - Section 4: Hydrology (NEH-4, SCS, August 1972) contains a detailed description of the development and use of the curve number method.

SCS has developed "curve number" (CN) values based on soil type and land use. The combination of these two factors is called the "soil-cover complex." The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. SCS has classified over 4,000 soil types into these four soil groups. Table A3 shows the hydrologic soil group of most soils in the Puget Sound basin and provides a brief description of 'the four groups.

Table A6 shows the CNs, by land use description, for the four hydrologic soil groups. These numbers are for a 24-hour duration storm and typical antecedent soil moisture condition preceding 24-hour storms in Western Washington. Note these CNs are not, therefore, "average," but rather calibrated by the SCS for Western Washington and should not be used with "wet" or "dry" modifications. Modeling performed to calibrate to actual rainfall and/or runoff data should start with the original SCS CNs published in TR-55.

The following are important criteria/considerations for selection of CN values:

1. Many factors may affect the CN value for a given land use. For example, the movement of heavy equipment over bare ground may compact the soil so that it has a lesser infiltration rate and greater runoff potential than would be indicated by strict application of the CN value based on pre-development conditions at the site.

Table A3. Hydrologic Soil Groups for Soils in the Puget Sound Basin

Soil Type	Hydrologic Soil Group	Soil Type	Hydrologic Soil Group
Agnew	C	Colter	C
Ahl	B	Custer	ND
Aits	C	Dabob	ND
Alderwood	C	Delphi	D
Arents, Alderwood	B	Dick	ND
Arents, Everett	B	Dimal	D
Ashoe	B	Dupont	D
Baldhill	B	Earlmont	C
Barneston	C	Edgewick	C
Baumgard	B	Eld	B
Beausite	B	Elwell	B
Belfast	C	Esquatzel	B
Bellingham	D	Everett	A
Bellingham variant	C	Everson	D
Boistfort	B	Galvin	D
Bow	D	Getchell	A
Briscot	D	Giles	B
Buckley	C	Godfrey	D
Bunker	B	Greenwater	A
Cagey	C	Grove	C
Carlsborg	ND	Harstine	C
Casey	ND	Hartnit	ND
Cassolary	C	Hoh	ND
Cathcart	B	Hoko	ND
Centralia	B	Hoodsport	ND
Chehalis	B	Hoogdal	C
Chesaw	A	Hoypus	ND
Cinebar	B	Huel	ND
Clallam	C	Indinanola	ND
Clayton	B	Jonas	B
Coastal beaches	variable	Jumps	ND
Kapowsin	C/D	Kalaloch	C
Katula	C	Renton	D
Kilchis	C	Republic	B
Kitsap	C	Riverwash	variable
Klaus	ND	Rober	C
Klone	ND	Salal	C
Lates	C	Salkum	B
Lebam	B	Sammamish	D
Lummi	ND	San Juan	ND
Lynnwood	ND	Scamman	D
Lystair	ND	Schneider	B
Mai	C	Seattle	D
Manley	B	Sekiu	ND
Mashel	B	Semiahmoo	D

Table A3. Hydrologic Soil Groups for Soils in the Puget Sound Basin (continued)

Soil Type	Hydrologic Soil Group	Soil Type	Hydrologic Soil Group
Maytown	C	Shalcar	D
McKenna	D	Shano	B
McMurray	ND	Shelton	C
Melbourne	B	Si	C
Menzel	ND	Sinclair	C
Mixed Alluvial	variable	Skipopa	D
Molson	B	Skykomish	B
Mukilteo	C/D	Snahopish	ND
Naff	B	Snohomish	D
Nargar	A	Solduc	B
National	ND	Solleka	ND
Neilton	A	Spana	D
Newberg	B	Spanaway	A/B
Nisqually	B	Springdale	B
Nooksack	C	Sulsavar	B
Norma	C/D	Sultan	C
Ogarty	C	Sultan variant	B
Olete	ND	Surnas	C
Olomount	C	Swantown	ND
Olympic	B	Tacorna	D
Orcas	D	Tanwax	ND
Oridia	D	Tealwhit	ND
Orting	ND	Tenino	C
Oso	C	Tisch	D
Ovall	C	Tokul	ND
Pastik	C	Townsend	C
Pheeney	C	Triton	ND
Phelan	ND	Tukwila	D
Pilchuck	C	Tukey	ND
Potchub	C	Urban	Variable
Poulsbo	C	Vailton	B
Prather	C	Verlot	C
Puget	D	Wapato	ND
Puyallup	B	Warden	B
Queets	ND	Whidbey	ND
Quilcene	ND	Wilkeson	B
Ragnar	B	Winston	A
Rainier	C	Woodinville	B
Raught	B	Yelm	C
Reed	ND	Zynbar	B

2. CN values can be area-weighted when they apply to pervious areas of similar CNs (within 20 CN points). However, high CN areas should not be combined with low CN areas. In this case, separate hydrographs should be generated and summed to form one hydrograph unless the low CN areas are less than 15 percent of the subbasin.

3. Separate CN values must be selected for the pervious and impervious areas of an urban basin or subbasin. For single family residential areas the percent impervious given in Table A4 shall be used to compute the respective pervious and impervious areas. For proposed commercial areas, PUDs etc., the percent impervious must be computed from the site plan. For all other land uses, the percent impervious must be estimated from best available aerial topography and/or field reconnaissance. The pervious area CN value shall be a weighted average of all the pervious area CNs within the subbasin. The impervious area CN value shall be 98.

4. For storm duration other than 24 hours, an adjustment must be made to the CN values given in Table A4. Based on information obtained from SCS, the following equation shall be used for adjusting these CNs for the seven-day design storm:

$$CN\ (7\ day) = 0.1549\ CN + 0.8451\ ((CN^{2.365}/631.8) + 15)$$

Example: The following is an example of how CN values are selected for a sample project.

Select CNs for the following development:

Existing Land Use - forest (undisturbed)
Future Land Use - residential plat (3.6 DU/GA)
Basin Size - 10 acres
Soil Type - 80% Alderwood, 20% Ragnor

Table A3 shows that Alderwood soil belongs to the "C" hydrologic soil group and Ragnor soil belongs to the "B" group. Therefore, for the existing condition, CNs of 76 and 64 are read from Table A4 and area-weighted to obtain a CN value of 74. For the developed condition with 3.6 DU/GA the percent impervious of 39 percent is interpolated from Table A4 and used to compute pervious and impervious areas of 6.1 acres and 3.9 acres, respectively. The 6.1 acres of pervious area consists of residential yards and lawns covering the same proportions of Alderwood and Everett soil (80 percent and 20 percent respectively). Therefore, CNs of 90 and 85 are read from Table A4 and area-weighted to obtain a pervious area CN value of 89. The impervious area CN value is 98. The result of this example is summarized below:

On-Site Condition	Existing	Developed
Land use	Forest	Residential
Pervious area	10 ac.	6.1 ac.
CN of pervious area	74	89
Impervious area	0 ac.	3.9 ac.
CN of impervious area	---	98

3.2.3 SCS Curve Number Equations

The rainfall-runoff equations of the SCS curve number method relates a land area runoff depth (precipitation excess) to the precipitation it receives and to its natural storage capacity, as follows:

Table A4. SCS Western Washington Runoff Curve Numbers

(Published by SCS in 1982)

Runoff curve numbers for selected agricultural, suburban and urban land use for Type 1A rainfall distribution, 24-hour storm duration.

LAND USE DESCRIPTION		**CURVE NUMBERS BY HYDROLOGIC SOIL GROUP** A	B	C	D
Cultivated land (l):	winter condition	86	91	94	95
Mountain open areas:	low growing brush & grasslands	74	82	89	92
Meadow or pasture:		65	78	85	89
Wood or forest land:	undisturbed	42	64	76	81
wood or forest land:	young second growth or brush	55	72	81	86
Orchard:	with cover crop	81	88	92	94
Open spaces, lawns, parks, golf courses, cemeteries, landscaping.					
Good condition:	grass cover on ≥75% of the area	68	80	86	90
Fair condition:	grass cover on 50-75% of the area	77	85	90	92
Gravel roads & parking lots:		76	85	89	91
Dirt roads & parking lots:		72	82	87	89
Impervious surfaces, pavement, roofs etc.		98	98	98	98
open water bodies:	lakes, wetlands, ponds etc	100	100	100	100
Single family residential (2)		Separate curve number shall be selected for pervious & impervious portions of the site or basin			
Dwelling Unit/Gross Acre	%impervious(3)				
1.0 DU/GA	15				
1.5 DU/GA	20				
2.0 DU/GA	25				
2.5 DU/GA	30				
3.0 DU/GA	34				
3.5 DU/GA	38				
4.0 DU/GA	42				
4.5 DU/GA	46				
5.0 DU/GA	48				
5.5 DU/GA	50				
6.0 DU/GA	52				
6.5 DU/GA	54				
7.0 DU/GA	56				
PUDs, condos, apartments, commercial businesses & industrial areas	% impervious must be computed				

(1) For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Sec. 4, Hydrology, Chapter 9, August 1972.
(2) Assumes roof and driveway runoff is directed into street/storm system.
(3) The remaining pervious areas (lawn) are considered to be in good condition for these curve numbers.

$Q_d = (P_R - 0.2S)^2 / (P_R + 0.8S)$ for $P_R \geq 0.2S$
and $Q_d = 0$ for $P_R < 0.2S$

where:

Q_d = runoff depth in inches over the area,
P_R = precipitation depth in inches over the area, and
S = potential maximum natural detention, in inches over the area, due to infiltration, storage, etc.

The area's potential maximum detention, S, is related to its curve number, CN:

$S = (1000/CN) - 10$

The combination of the above equations allows for estimation of the total runoff volume by computing total runoff depth, Q_d, given the total precipitation depth, P_R. For example**,** if the curve number of the area is 70, then the value of S is 4.29. With a total precipitation for the design event of 2.0 inches, the total runoff depth would be:

$Q_d = [2.0 - 0.2\ (4.29)]^2/[2.0 + 0.8\ (4.29)] = \underline{0.24 \text{ inches}}$

This computed runoff represents inches over the tributary area. Therefore, the total volume of runoff is found by multiplying Q_d by the area (with necessary conversions):

Total runoff Volume (cu. ft.) = 3,630 (cu. ft./ac. in.) x Q_d (in) x A (ac)

If the area is 10 acres, the total runoff volume is:

3,630 cu. ft./ac. in. x 0.24 in. x 10 ac. = <u>8,712 cu. ft.</u>

When developing the runoff hydrograph, the above equation for Q_d is used to compute the incremental runoff depth for each time interval from the incremental precipitation depth given by the design storm hyetograph. This time distribution of runoff depth is often referred to as the precipitation excess and provides the basis for synthesizing the runoff hydrograph.

3.2.4 Travel Time and Time of Concentration for Use in Hydrograph Analysis
(based on the methods described in Chapter 3, SCS TR-55)

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is the time it takes for runoff to travel from the hydraulically most distant point of the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system. T_c influences the shape and peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing peak discharge. T_c can be increased as a result of either ponding behind small or inadequate drainage systems (including storm drain inlets and road culverts) or by reduction of land slope through grading.

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow or some combination of these. The type of flow that occurs is best determined by field inspection.

Travel time (T_t) is the ratio of flow length to flow velocity:

$T_t = L/60V$

where:

T_t = travel time (minutes)
L = flow length (feet)
V = average velocity (feet/sec) and
60 = conversion factor from seconds to minutes

Time of concentration (T_c) is the sum of T_t, values for the various consecutive flow segments.

$T_c = T_{t1} + T_{t2} + \ldots T_{tM}$

where:

T_c = time of concentration (minutes) and
M = number of flow segments

Sheet Flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (n_s) (a modified Manning's effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges and rocks; and erosion and transportation of sediment) is used. These n. values are for very shallow flow depths of about 0.1 foot and are only used for travel lengths up to 300 feet. Table A5 gives Manning's n, values for sheet flow for various surface conditions.

For sheet flow of up to 300 feet, use Manning's kinematic solution to directly compute T_t.

$$T_t = \frac{0.42\,(n_s L)^{0.8}}{(P_2)^{0.527}(S_o)^{0.4}}$$

where:

T_t = travel time (min),
n_s = sheet flow Manning's effective roughness coefficient (from Table A5)
L = flow length (ft)
P_2 = 2-year, 24-hour rainfall (in), and
S_o = slope of hydraulic grade line (land slope, ft/ft)

Velocity Equation

A commonly used method of computing average velocity of flow, once it has measurable depth, is the following equation:

$$V = k\,(s_o)^{1/2}$$

where:

V = velocity (ft/s)
k = time of concentration velocity factor (ft/s)
s_o = slope of flow path (ft/ft)

"k" is computed for various land covers and channel characteristics with assumptions made for hydraulic radius using the following rearrangement of Manning's equation:

$$k = (1.49 (R)^{0.667}) / n$$

where:

R = an assumed hydraulic radius
n = Manning's roughness coefficient for open channel flow

Shallow Concentrated Flow: After a maximum of 300 feet, sheet flow is assumed to become shallow concentrated flow. The average velocity for this flow can be calculated using the k, values from Table A5 in which average velocity is a function of watercourse slope and type of channel. After computing the average velocity using the Velocity Equation above, the travel time (T_t) for the shallow concentrated flow segment can be computed using the Travel Time Equation described above.

Open Channel Flow: Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where lines indicating streams appear (in blue) on United States Geological Survey (USGS) quadrangle sheets. The k_c values from Table A5 used in the Velocity Equation above or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bankfull conditions. After average velocity is computed the travel time (T_t) for the channel segment can be computed using the Travel Time Equation above.

Lakes or Wetlands: Sometimes it is necessary to estimate the velocity of flow through a lake or wetland at the outlet of a watershed. This travel time is normally very small and can be assumed as zero.

Limitations: The following limitations apply in estimating travel time (T_t)

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet.

- In watersheds with storm drains, carefully identify the appropriate hydraulic flow path to estimate Tc. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or nonpressure flow.

- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. A hydrograph should be developed to this point.

Example: The following is an example of travel time and time of concentration calculations.

Given: An existing drainage basin having a selected flow route composed of the following five segments. Note: Drainage basin is in Federal Way and has a P_2 = 2. 1 inches.

Segment 1: L = 200 ft. Forest with dense brush (sheet flow)
0.03 ft/ft, $n_s = 0.80$

Segment 2: L = 300 ft. Pasture (shallow concentrated flow)
s_o = 0.04 ft/ft, $k_s = 11$

Segment 3: L = 50 ft. Small pond (year around)
s_o = 0.00 ft/ft, $k_c = 0$

Segment 4:	L	=	300 ft. Grassed waterway (intermittent channel)
	s_o	=	0.05 ft/ft, $k_c = 17$
Segment 5:	L	=	500 ft. Grass-lined stream (continuous)
	s_o	=	0.02 ft/ft, $k_c = 27$

Table A5. "n" and "k" Values Used in Time Calculations for Hydrographs

"n_s" Sheet Flow Equation Manning's Values (for the initial 300 ft. of travel)

	n_s
Smooth surfaces (concrete, asphalt, gravel, or bare hand packed soil)	0.011
Fallow fields or loose soil surface (no residue)	0.05
Cultivated soil with residue cover ($s \leq 0.20$ ft/ft)	0.06
Cultivated soil with residue cover ($s > 0.20$ ft/ft)	0.17
Short prairie grass and lawns	0.15
Dense grasses	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods or forest with light underbrush	0.40
Woods or forest with dense underbrush	0.80

*Manning values for sheet flow only, from Overton and Meadows 1976 (See TR-55, 1986)

"k" Values Used in Travel Time/Time of Concentration Calculations

Shallow Concentrated Flow (After the initial 300 ft. of sheet flow, R = 0.1)	k_c
1. Forest with heavy ground litter and meadows (n = 0.10)	3
2. Brushy ground with some trees (n = 0.060)	5
3. Fallow or minimum tillage cultivation (n = 0.040)	8
4. High grass (n = 0.035)	9
5. Short grass, pasture and lawns (n = 0.030)	11
6. Nearly bare ground (n = 0.25)	13
7. Paved and gravel areas (n = 0.012)	27

Channel Flow (intermittent) (At the beginning of visible channels R = 0.2)	k_c
1. Forested swale with heavy ground litter (n = 0.10)	5
2. Forested drainage course/ravine with defined channel bed (n = 0.050)	10
3. Rock-lined waterway (n = 0.035)	15
4. Grassed waterway (n = 0.030)	17
5. Earth-lined waterway (n = 0.025)	20
6. CMP pipe (n = 0.024)	21
7. Concrete pipe (0.012)	42
8. Other waterways and pipe 0.508/n	

Channel Flow (Continuous stream, R = 0.4)	k_c
9. Meandering stream with some pools (n = 0.040)	20
10. Rock-lined stream (n = 0.035)	23
11. Grass-lined stream (n = 0.030)	27
12. Other streams, man-made channels and pipe	0.807/n**

Table A6. Values of the Roughness Coefficient "n"

Type of Channel and Description	Manning's "n" (Normal)
A. Constructed Channels	
a. Earth, straight and uniform	
1. Clean; recently completed	0.018
2. Gravel, uniform section, clean	0.025
3. With short grass, few weeds	0.027
b. Earth, winding and sluggish	0.025
1. No vegetation	0.025
2. Grass, some weeds	0.030
3. Dense weeds or aquatic plants in deep channels	0.035
4. Earth bottom and rubble sides	0.030
5. Stony bottom and weedy banks	0.035
6. Cobble bottom and clean sides	0.040
c. Rock lined	
1. Smooth and uniform	0.035
2. Jagged and irregular	0.040
d. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.080
2. Clean bottom, brush on sides	0.050
3. Same, highest stage of flow	0.070
4. Dense brush, high stage	0.100
B. Natural Streams	
B-1 Minor streams (top width at flood stage < 100 ft.)	
a. Streams on plain	
1. Clean, straight, full stage no rifts or deep pools	0.030
2. Same as above, but more stones and weeds	0.035
3. Clean, winding, some pools and shoals	0.040
4. Same as above, but some weeds	0.040
5. Same as 4, but more stones	0.050
6. Sluggish reaches, weedy deep pools	0.070
7. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.100
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages	
1. Bottom: gravel, cobbles, and few boulders	0.040
2. Bottom: cobbles with large boulders	0.050
B-2 Flood plains	
a. Pasture, no brush	
1. Short grass	0.030
2. High grass	0.035
b. Cultivated areas	
1. No crop	0.030
2. Mature row crops	0.035
3. Mature field crops	0.040
c. Brush	
1. Scattered brush, heavy weeds	0.050
2. Light brush and trees	0.060
3. Medium to dense brush	0.070
4. Heavy, dense brush	0.100
d. Trees	
1. Dense willows, straight	0.150
2. Cleared land with tree stumps, no sprouts	0.040
3. Same as above, but with heavy growth of sprouts	0.060
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.100
5. Same as above, but with flood stage reaching branches	0.120

Calculate travel times (T_t's) for each reach and then sum them to calculate the drainage basin time of concentration (T_c).

Segment 1: Sheet flow (L <300 feet), $T_t = \dfrac{\underline{0.42\,(n_s L)}^{0.8}}{(P_2)^{0.5}(s_o)^{0.4}}$

$$T_1 = \frac{\underline{(0.42)[(0.80)(200)]}^{0.8}}{(2.1)^{0.527}\,(0.03)^{0.4}} = 68\ \underline{\text{minutes}}$$

Segment 2: Shallow concentrated flow V = ks (so)1/2

$$V_2 = (11)\,(0.04)^{1/2} = 2.2\ \text{ft/s}$$
$$T_2 = L/60V = (300)/(60*2.2) = 2\ \text{minutes}$$

Segment 3: Flat water surface

$$T_3 = \underline{0\ \text{minutes}}$$

Segment 4: Intermittent channel flow

$$V_4 = (17)\,(0.05)^{1/2} = 3.8\ \text{ft/s}$$
$$T_4 = (300)/(60*3.8) = 1\ \text{minute}$$

Segment 5: Continuous stream

$$V_5 = (27)\,(0.02)^{1/2} = 3.8\ \text{ft/s}$$
$$T_5 = (500)/(60*3.8) = 2\ \text{minutes}$$

Total Time

$$T_C = T_1 + T_2 + T_3 + T_4 + T_5$$
$$T_c = 68 + 2 + 0 + 1 + 2 = \underline{73\ \text{minutes}}$$

It is important to note how the initial sheet flow segment's travel time dominates the time of concentration computation. This will nearly always be the case for relatively small drainage basins and in particular the existing site conditions. This also illustrates the significant impact urbanization has on the surface runoff portion of the hydrologic process.

A3.3 Hydrograph Synthesis

This section presents a description of the Santa Barbara Urban Hydrograph (SBUH) method.

The Santa Barbara Urban Hydrograph Method

The SBUH method, like the Soil Conservation Service Urban Hydrograph (SCSUH) method, is based on the curve number (CN) approach, and also uses SCS equations for computing soil absorption and precipitation excess. The SCSUH method works by converting the incremental runoff depths (precipitation excess) for a given basin and design storm hydrographs of equal time base according to basin time of concentration and adds them to form the runoff hydrograph. The SBUH method, on the other hand, converts the incremental runoff depths into instantaneous hydrographs which are then routed through an imaginary reservoir with a time delay equal to the basin time of concentration.

The SBUH method was developed by the Santa Barbara County Flood Control and Water Conservation District, California. The SBUH method directly computes a runoff hydrograph without going through an intermediate process (unit hydrograph) as the SCSUH method does. By comparison, the calculation steps of the SBUH method are much simpler and can be programmed on a calculator or a spreadsheet program.

The SBUH method uses two steps to Synthesize the runoff hydrograph:

Step one - computing the instantaneous hydrograph, and Step two - computing the runoff hydrograph.

The instantaneous hydrograph, I(t), in cfs, at each time step, dt, is computed as follows:

$$I(t) = 60.5\, R(t)\, A/dt$$

where:

R(t) = total runoff depth (both impervious and pervious runoffs) at time increment dt, in inches (also known as precipitation excess)

A = area in acres
dt = time interval in minutes*

* NOTE: A maximum time interval of 10 minutes should be used for all design storms of 24-hour duration. A maximum time interval of 60 minutes should be used for the 100-year, 7-day design storm.

The runoff hydrograph, Q(t), is then obtained by routing the instantaneous hydrograph I(t), through an imaginary reservoir with a time delay equal to the time of concentration, T., of the drainage basin. The following equation estimates the routed flow, Q(t):

$$Q(t+l) = Q(t) + w[I(t) + I(t+l) - 2Q(t)]$$

where:

$w = dt/ (2T_c + dt)$
dt = time interval in minutes

<u>Example</u>: To illustrate the SBUH method Table A7 shows runoff hydrograph values computed by this method for both existing and developed conditions. The example calculates design flows for sizing a *treatment facility* using the standard SCS Type 1A Design Storm Hyetograph. In this example, a one acre site was assumed to be half impervious and half impervious in the developed condition. The rainfall volume (Pt) for a six-month storm (1.075 inches) was used. Note, this example was prepared using the Microsoft Excel spreadsheet program and illustrates how the method can be used with a personal computer. The method of analysis would be identical for sizing a *treatment facility* except that the standard SEATTLE-modified SCS Type 1A hyetograph would be used. This is illustrated in Table A8, using the same initial conditions but the SEATTLE hyetograph.

Table A7. SBUH Hyedrograph Values for Developed Site Condition (Using Standard SCS Type 1A)

Given:	Total Area = 1.0 acres	Pt = 1.075 inches (6-mo, 24-hour event)	dt = 10 minutes	Tc = 10 minutes
	PERVIOUS AREA:	Area = 0.5 acres	CN = 85	S = 1.76 0.2S = 0.35
	IMPERVIOUS AREA:	Area = 0.5 acres	CN = 98	S = 0.20 0.2S = 0.04

Column (3) = SCS Type 1A (Seattle Variant) rainfall distribution
Column (4) = Column (3) * Pt
Column (5) = Accumulated sum of Column (4)
Column (6) = (If P ≤ 0.2S) = 0, (if P ≥ 0.2S) = ((Column (5) – 0.2S)^2/(Column (5) + 0.8S) where the Pervious Area S value is used
Column (7) = Column (6) of present time step – Column (6) of pervious time step
Column (8) = Same as Column (6) except use Imperious Area S value
Column (9) = Column (8) of present time step – Column (8) of pervious time step
Column (10) = ((Pervious Area/Total Area) * Column (7)) + ((Impervious Area/Total Area) * Column (9))
Column (11) = (60.5 * Column (10) * Total Area)/dt, where dt = 10 minutes
Column (12) = Column (12) of previous time step + w * [{Column (11) of previous time step + column (11) of present time step) – (2 * Column (12) of previous time step)], where w = routing constant = dt/(2Tc + dt) = 0.0641

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0	0	0.000	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00
1	10	0.004	0.0043	0.004	0.000	0.000	0.000	0.000	0.000	0.00	0.00
2	20	0.004	0.0043	0.009	0.000	0.000	0.000	0.000	0.000	0.00	0.00
3	30	0.004	0.0043	0.013	0.000	0.000	0.000	0.000	0.000	0.00	0.00
4	40	0.004	0.0043	0.017	0.000	0.000	0.000	0.000	0.000	0.00	0.00
5	50	0.004	0.0043	0.022	0.000	0.000	0.000	0.000	0.000	0.00	0.00
6	60	0.004	0.0043	0.026	0.000	0.000	0.000	0.000	0.000	0.00	0.00
7	70	0.004	0.0043	0.030	0.000	0.000	0.000	0.000	0.000	0.00	0.00
8	80	0.004	0.0043	0.034	0.000	0.000	0.000	0.000	0.000	0.00	0.00
9	90	0.004	0.0043	0.039	0.000	0.000	0.000	0.000	0.000	0.00	0.00
10	100	0.004	0.0043	0.043	0.000	0.000	0.000	0.000	0.000	0.00	0.00
11	110	0.005	0.0054	0.048	0.000	0.000	0.000	0.000	0.000	0.00	0.00
12	120	0.005	0.0054	0.054	0.000	0.000	0.001	0.001	0.000	0.00	0.00
13	130	0.005	0.0054	0.059	0.000	0.000	0.002	0.001	0.000	0.00	0.00
14	140	0.005	0.0054	0.065	0.000	0.000	0.002	0.001	0.000	0.00	0.00
15	150	0.005	0.0054	0.070	0.000	0.000	0.004	0.001	0.001	0.00	0.00
16	160	0.005	0.0054	0.075	0.000	0.000	0.005	0.001	0.001	0.00	0.00
17	170	0.006	0.0065	0.082	0.000	0.000	0.007	0.002	0.001	0.01	0.00
18	180	0.006	0.0065	0.088	0.000	0.000	0.009	0.002	0.001	0.01	0.00
19	190	0.006	0.0065	0.095	0.000	0.000	0.011	0.002	0.001	0.01	0.00
20	200	0.006	0.0065	0.101	0.000	0.000	0.014	0.003	0.001	0.01	0.01
21	210	0.006	0.0065	0.108	0.000	0.000	0.016	0.003	0.001	0.01	0.01
22	220	0.006	0.0065	0.114	0.000	0.000	0.019	0.003	0.001	0.01	0.01
23	230	0.007	0.0075	0.121	0.000	0.000	0.023	0.004	0.002	0.01	0.01
24	240	0.007	0.0075	0.129	0.000	0.000	0.027	0.004	0.002	0.01	0.01
25	250	0.007	0.0075	0.137	0.000	0.000	0.031	0.004	0.002	0.01	0.01
26	260	0.007	0.0075	0.144	0.000	0.000	0.035	0.004	0.002	0.01	0.01
27	270	0.007	0.0075	0.152	0.000	0.000	0.039	0.004	0.002	0.01	0.01
28	280	0.007	0.0075	0.159	0.000	0.000	0.043	0.004	0.002	0.01	0.01

Table A7. SBUH Hyedrograph Values for Developed Site Condition (Using Standard SCS Type 1A) (continued)

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
29	290	0.008	0.0088	0.168	0.000	0.000	0.049	0.005	0.003	0.02	0.01
30	300	0.008	0.0088	0.177	0.000	0.000	0.054	0.006	0.003	0.02	0.01
31	310	0.008	0.0088	0.186	0.000	0.000	0.060	0.006	0.003	0.02	0.01
32	320	0.008	0.0088	0.194	0.000	0.000	0.066	0.006	0.003	0.02	0.02
33	330	0.008	0.0088	0.203	0.000	0.000	0.072	0.006	0.003	0.02	0.02
34	340	0.008	0.0088	0.212	0.000	0.000	0.078	0.006	0.003	0.02	0.02
35	350	0.010	0.0102	0.222	0.000	0.000	0.085	0.007	0.004	0.02	0.02
36	360	0.010	0.0102	0.232	0.000	0.000	0.093	0.007	0.004	0.02	0.02
37	370	0.010	0.0102	0.243	0.000	0.000	0.100	0.008	0.004	0.02	0.02
38	380	0.010	0.0102	0.253	0.000	0.000	0.108	0.008	0.004	0.02	0.02
39	390	0.010	0.0102	0.263	0.000	0.000	0.116	0.008	0.004	0.02	0.02
40	400	0.010	0.0102	0.273	0.000	0.000	0.124	0.008	0.004	0.02	0.02
41	410	0.013	0.0144	0.288	0.000	0.000	0.135	0.011	0.006	0.03	0.02
42	420	0.013	0.0144	0.302	0.000	0.000	0.147	0.012	0.006	0.03	0.03
43	430	0.013	0.0144	0.316	0.000	0.000	0.158	0.012	0.006	0.04	0.03
44	440	0.018	0.0194	0.336	0.000	0.000	0.174	0.016	0.008	0.05	0.03
45	450	0.018	0.0194	0.355	0.000	0.000	0.191	0.016	0.008	0.05	0.04
46	460	0.034	0.0366	0.392	0.001	0.001	0.222	0.031	0.016	0.10	0.05
47	470	0.054	0.0581	0.450	0.005	0.004	0.273	0.051	0.028	0.17	0.07
48	480	0.027	0.0290	0.479	0.008	0.003	0.299	0.026	0.015	0.09	0.09
49	490	0.018	0.0194	0.498	0.011	0.003	0.316	0.017	0.010	0.06	0.09
50	500	0.013	0.0144	0.513	0.013	0.002	0.329	0.013	0.008	0.05	0.08
51	510	0.013	0.0144	0.527	0.016	0.002	0.342	0.013	0.008	0.05	0.07
52	520	0.013	0.0144	0.541	0.018	0.003	0.356	0.013	0.008	0.05	0.06
53	530	0.009	0.0095	0.551	0.020	0.002	0.364	0.009	0.005	0.03	0.05
54	540	0.009	0.0095	0.560	0.022	0.002	0.373	0.009	0.005	0.03	0.05
55	550	0.009	0.0095	0.570	0.024	0.002	0.382	0.009	0.005	0.03	0.04
56	560	0.009	0.0095	0.579	0.026	0.002	0.390	0.009	0.005	0.03	0.04
57	570	0.009	0.0095	0.589	0.028	0.002	0.399	0.009	0.005	0.03	0.04
58	580	0.009	0.0095	0.598	0.030	0.002	0.408	0.009	0.005	0.03	0.04
59	590	0.009	0.0095	0.608	0.032	0.002	0.417	0.009	0.005	0.03	0.04
60	600	0.009	0.0095	0.617	0.034	0.002	0.426	0.009	0.006	0.03	0.03
61	610	0.009	0.0095	0.627	0.037	0.002	0.434	0.009	0.006	0.03	0.03
62	620	0.009	0.0095	0.636	0.039	0.002	0.443	0.009	0.006	0.03	0.03
63	630	0.009	0.0095	0.645	0.042	0.002	0.452	0.009	0.006	0.03	0.03
64	640	0.009	0.0095	0.655	0.044	0.003	0.461	0.009	0.006	0.03	0.03
65	650	0.007	0.0077	0.663	0.046	0.002	0.468	0.007	0.005	0.03	0.03
66	660	0.007	0.0077	0.670	0.048	0.002	0.475	0.007	0.005	0.03	0.03
67	670	0.007	0.0077	0.678	0.051	0.002	0.483	0.007	0.005	0.03	0.03
68	680	0.007	0.0077	0.686	0.053	0.002	0.490	0.007	0.005	0.03	0.03
69	690	0.007	0.0077	0.694	0.055	0.002	0.497	0.007	0.005	0.03	0.03
70	700	0.007	0.0077	0.701	0.057	0.002	0.505	0.007	0.005	0.03	0.03

Table A7. SBUH Hyedrograph Values for Developed Site Condition (Using Standard SCS Type 1A) (continued)

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
71	710	0.007	0.0077	0.709	0.060	0.002	0.512	0.007	0.005	0.03	0.03
72	720	0.007	0.0077	0.717	0.062	0.002	0.519	0.007	0.005	0.03	0.03
73	730	0.007	0.0077	0.725	0.065	0.002	0.527	0.007	0.005	0.03	0.03
74	740	0.007	0.0077	0.732	0.067	0.002	0.534	0.007	0.005	0.03	0.03
75	750	0.007	0.0077	0.740	0.070	0.003	0.541	0.007	0.005	0.03	0.03
76	760	0.007	0.0077	0.748	0.072	0.003	0.549	0.007	0.005	0.03	0.03
77	770	0.006	0.0061	0.754	0.074	0.002	0.554	0.006	0.004	0.02	0.03
78	780	0.006	0.0061	0.760	0.076	0.002	0.560	0.006	0.004	0.02	0.03
79	790	0.006	0.0061	0.766	0.078	0.002	0.566	0.006	0.004	0.02	0.03
80	800	0.006	0.0061	0.772	0.081	0.002	0.572	0.006	0.004	0.02	0.03
81	810	0.006	0.0061	0.778	0.083	0.002	0.578	0.006	0.004	0.02	0.03
82	820	0.006	0.0061	0.785	0.085	0.002	0.584	0.006	0.004	0.02	0.02
83	830	0.006	0.0061	0.791	0.087	0.002	0.589	0.006	0.004	0.02	0.02
84	840	0.006	0.0061	0.797	0.089	0.002	0.595	0.006	0.004	0.02	0.02
85	850	0.006	0.0061	0.803	0.091	0.002	0.601	0.006	0.004	0.02	0.02
86	860	0.006	0.0061	0.809	0.094	0.002	0.607	0.006	0.004	0.02	0.02
87	870	0.006	0.0061	0.815	0.096	0.002	0.613	0.006	0.004	0.02	0.02
88	880	0.006	0.0061	0.821	0.098	0.002	0.619	0.006	0.004	0.02	0.02
89	890	0.005	0.0054	0.827	0.100	0.002	0.624	0.005	0.004	0.02	0.02
90	900	0.005	0.0054	0.832	0.102	0.002	0.629	0.005	0.004	0.02	0.02
91	910	0.005	0.0054	0.837	0.104	0.002	0.634	0.005	0.004	0.02	0.02
92	920	0.005	0.0054	0.843	0.106	0.002	0.639	0.005	0.004	0.02	0.02
93	930	0.005	0.0054	0.848	0.109	0.002	0.644	0.005	0.004	0.02	0.02
94	940	0.005	0.0054	0.854	0.111	0.002	0.650	0.005	0.004	0.02	0.02
95	950	0.005	0.0054	0.859	0.113	0.002	0.655	0.005	0.004	0.02	0.02
96	960	0.005	0.0054	0.864	0.115	0.002	0.660	0.005	0.004	0.02	0.02
97	970	0.005	0.0054	0.870	0.117	0.002	0.665	0.005	0.004	0.02	0.02
98	980	0.005	0.0054	0.875	0.119	0.002	0.670	0.005	0.004	0.02	0.02
99	990	0.005	0.0054	0.880	0.121	0.002	0.675	0.005	0.004	0.02	0.02
100	1000	0.005	0.0054	0.886	0.124	0.002	0.681	0.005	0.004	0.02	0.02
101	1010	0.004	0.0043	0.890	0.125	0.002	0.685	0.004	0.003	0.02	0.02
102	1020	0.004	0.0043	0.894	0.127	0.002	0.689	0.004	0.003	0.02	0.02
103	1030	0.004	0.0043	0.899	0.129	0.002	0.693	0.004	0.003	0.02	0.02
104	1040	0.004	0.0043	0.903	0.131	0.002	0.697	0.004	0.003	0.02	0.02
105	1050	0.004	0.0043	0.907	0.133	0.002	0.701	0.004	0.003	0.02	0.02
106	1060	0.004	0.0043	0.912	0.134	0.002	0.705	0.004	0.003	0.02	0.02
107	1070	0.004	0.0043	0.916	0.136	0.002	0.710	0.004	0.003	0.02	0.02
108	1080	0.004	0.0043	0.920	0.138	0.002	0.714	0.004	0.003	0.02	0.02
109	1090	0.004	0.0043	0.924	0.140	0.002	0.718	0.004	0.003	0.02	0.02
110	1100	0.004	0.0043	0.929	0.142	0.002	0.722	0.004	0.003	0.02	0.02
111	1110	0.004	0.0043	0.933	0.144	0.002	0.726	0.004	0.003	0.02	0.02
112	1120	0.004	0.0043	0.937	0.145	0.002	0.730	0.004	0.003	0.02	0.02

Table A7. SBUH Hydrograph Values for Developed Site Condition (Using Standard SCS Type 1A) (continued)

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
113	1130	0.004	0.0043	0.942	0.147	0.002	0.734	0.004	0.003	0.02	0.02
114	1140	0.004	0.0043	0.946	0.149	0.002	0.739	0.004	0.003	0.02	0.02
115	1150	0.004	0.0043	0.950	0.151	0.002	0.743	0.004	0.003	0.02	0.02
116	1160	0.004	0.0043	0.955	0.153	0.002	0.747	0.004	0.003	0.02	0.02
117	1170	0.004	0.0043	0.959	0.155	0.002	0.751	0.004	0.003	0.02	0.02
118	1180	0.004	0.0043	0.963	0.157	0.002	0.755	0.004	0.003	0.02	0.02
119	1190	0.004	0.0043	0.967	0.159	0.002	0.759	0.004	0.003	0.02	0.02
120	1200	0.004	0.0043	0.972	0.161	0.002	0.764	0.004	0.003	0.02	0.02
121	1210	0.004	0.0043	0.976	0.163	0.002	0.768	0.004	0.003	0.02	0.02
122	1220	0.004	0.0043	0.980	0.165	0.002	0.772	0.004	0.003	0.02	0.02
123	1230	0.004	0.0043	0.985	0.167	0.002	0.776	0.004	0.003	0.02	0.02
124	1240	0.004	0.0043	0.989	0.169	0.002	0.780	0.004	0.003	0.02	0.02
125	1250	0.004	0.0043	0.993	0.170	0.002	0.784	0.004	0.003	0.02	0.02
126	1260	0.004	0.0043	0.998	0.172	0.002	0.789	0.004	0.003	0.02	0.02
127	1270	0.004	0.0043	1.002	0.174	0.002	0.793	0.004	0.003	0.02	0.02
128	1280	0.004	0.0043	1.006	0.176	0.002	0.797	0.004	0.003	0.02	0.02
129	1290	0.004	0.0043	1.011	0.179	0.002	0.801	0.004	0.003	0.02	0.02
130	1300	0.004	0.0043	1.015	0.181	0.002	0.805	0.004	0.003	0.02	0.02
131	1310	0.004	0.0043	1.019	0.183	0.002	0.809	0.004	0.003	0.02	0.02
132	1320	0.004	0.0043	1.023	0.185	0.002	0.814	0.004	0.003	0.02	0.02
133	1330	0.004	0.0043	1.028	0.187	0.002	0.818	0.004	0.003	0.02	0.02
134	1340	0.004	0.0043	1.032	0.189	0.002	0.822	0.004	0.003	0.02	0.02
135	1350	0.004	0.0043	1.036	0.191	0.002	0.826	0.004	0.003	0.02	0.02
136	1360	0.004	0.0043	1.041	0.193	0.002	0.830	0.004	0.003	0.02	0.02
137	1370	0.004	0.0043	1.045	0.195	0.002	0.834	0.004	0.003	0.02	0.02
138	1380	0.004	0.0043	1.049	0.197	0.002	0.839	0.004	0.003	0.02	0.02
139	1390	0.004	0.0043	1.054	0.199	0.002	0.843	0.004	0.003	0.02	0.02
140	1400	0.004	0.0043	1.058	0.201	0.002	0.847	0.004	0.003	0.02	0.02
141	1410	0.004	0.0043	1.062	0.203	0.002	0.851	0.004	0.003	0.02	0.02
142	1420	0.004	0.0043	1.066	0.205	0.002	0.855	0.004	0.003	0.02	0.02
143	1430	0.004	0.0043	1.071	0.208	0.002	0.860	0.004	0.003	0.02	0.02
144	1440	0.004	0.0043	1.075	0.210	0.002	0.864	0.004	0.003	0.02	0.02
	SUM	**1.000**	**1.075**	**88.314**	**10.844**	**0.210**	**64.208**	**0.864**	**0.537**	**3.247**	**3.194**

Table A8. SBUH Hydrograph Values for Developed Site Condition (Using SEATTLE-Modified SCS Type 1A)

Given: Total Area = 1.0 acres Pt = 1.075 inches (6-mo, 24-hour event) dt = 10 minutes Tc = 10 minutes
PERVIOUS AREA: Area = 0.5 acres CN = 85 S = 1.76 0.2S = 0.35
IMPERVIOUS AREA: Area = 0.5 acres CN = 98 S = 0.20 0.2S = 0.04

Column (3) = SCS Type 1A (Seattle Variant) rainfall distribution
Column (4) = Column (3) * Pt
Column (5) = Accumulated sum of Column (4)
Column (6) = (If P ≤ 0.2S) = 0, (if P ≥ 0.2S) = ((Column (5) – 0.2S)^2/(Column (5) + 0.8S) where the Pervious Area S value is used
Column (7) = Column (6) of present time step – Column (6) of pervious time step
Column (8) = Same as Column (6) except use Imperious Area S value
Column (9) = Column (8) of present time step – Column (8) of pervious time step
Column (10) = ((Pervious Area/Total Area) * Column (7)) + ((Impervious Area/Total Area) * Column (9))
Column (11) = (60.5 * Column (10) * Total Area)/dt, where dt = 10 minutes
Column (12) = Column (12) of previous time step + w * [{Column (11) of previous time step + column (11) of present time step) – (2 * Column (12) of previous time step)], where w = routing constant = dt/(2Tc + dt) = 0.0641

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0	0	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00
1	10	0.0040	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.00	0.00
2	20	0.0040	0.004	0.009	0.000	0.000	0.000	0.000	0.000	0.00	0.00
3	30	0.0040	0.004	0.013	0.000	0.000	0.000	0.000	0.000	0.00	0.00
4	40	0.0040	0.004	0.017	0.000	0.000	0.000	0.000	0.000	0.00	0.00
5	50	0.0040	0.004	0.022	0.000	0.000	0.000	0.000	0.000	0.00	0.00
6	60	0.0040	0.004	0.026	0.000	0.000	0.000	0.000	0.000	0.00	0.00
7	70	0.0040	0.004	0.030	0.000	0.000	0.000	0.000	0.000	0.00	0.00
8	80	0.0040	0.004	0.034	0.000	0.000	0.000	0.000	0.000	0.00	0.00
9	90	0.0040	0.004	0.039	0.000	0.000	0.000	0.000	0.000	0.00	0.00
10	100	0.0040	0.004	0.043	0.000	0.000	0.000	0.000	0.000	0.00	0.00
11	110	0.0050	0.005	0.048	0.000	0.000	0.000	0.000	0.000	0.00	0.00
12	120	0.0050	0.005	0.054	0.000	0.000	0.001	0.001	0.000	0.00	0.00
13	130	0.0050	0.005	0.059	0.000	0.000	0.002	0.001	0.000	0.00	0.00
14	140	0.0050	0.005	0.065	0.000	0.000	0.002	0.001	0.000	0.00	0.00
15	150	0.0050	0.005	0.070	0.000	0.000	0.004	0.001	0.001	0.00	0.00
16	160	0.0050	0.005	0.075	0.000	0.000	0.005	0.001	0.001	0.00	0.00
17	170	0.0060	0.006	0.082	0.000	0.000	0.007	0.002	0.001	0.01	0.00
18	180	0.0060	0.006	0.088	0.000	0.000	0.009	0.002	0.001	0.01	0.01
19	190	0.0060	0.006	0.095	0.000	0.000	0.011	0.002	0.001	0.01	0.01
20	200	0.0060	0.006	0.101	0.000	0.000	0.014	0.003	0.001	0.01	0.01
21	210	0.0060	0.006	0.108	0.000	0.000	0.016	0.003	0.001	0.01	0.01
22	220	0.0060	0.006	0.114	0.000	0.000	0.019	0.003	0.001	0.01	0.01
23	230	0.0070	0.008	0.121	0.000	0.000	0.023	0.004	0.002	0.01	0.01
24	240	0.0070	0.008	0.129	0.000	0.000	0.027	0.004	0.002	0.01	0.01
25	250	0.0070	0.008	0.137	0.000	0.000	0.031	0.004	0.002	0.01	0.01
26	260	0.0070	0.008	0.144	0.000	0.000	0.035	0.004	0.002	0.01	0.01
27	270	0.0070	0.008	0.152	0.000	0.000	0.039	0.004	0.002	0.01	0.01
28	280	0.0070	0.008	0.159	0.000	0.000	0.043	0.004	0.002	0.01	0.01

Table A8. SBUH Hydrograph Values for Developed Site Condition (Using SEATTLE-Modified SCS Type 1A) (continued)

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
29	290	0.0082	0.009	0.168	0.000	0.000	0.049	0.005	0.003	0.02	0.01
30	300	0.0082	0.009	0.177	0.000	0.000	0.054	0.006	0.003	0.02	0.02
31	310	0.0082	0.009	0.186	0.000	0.000	0.060	0.006	0.003	0.02	0.02
32	320	0.0082	0.009	0.194	0.000	0.000	0.066	0.006	0.003	0.02	0.02
33	330	0.0082	0.009	0.203	0.000	0.000	0.072	0.006	0.003	0.02	0.02
34	340	0.0082	0.009	0.212	0.000	0.000	0.078	0.006	0.003	0.02	0.02
35	350	0.0095	0.010	0.222	0.000	0.000	0.085	0.007	0.004	0.02	0.02
36	360	0.0095	0.010	0.232	0.000	0.000	0.093	0.007	0.004	0.02	0.02
37	370	0.0095	0.010	0.243	0.000	0.000	0.100	0.008	0.004	0.02	0.02
38	380	0.0095	0.010	0.253	0.000	0.000	0.108	0.008	0.004	0.02	0.02
39	390	0.0095	0.010	0.263	0.000	0.000	0.116	0.008	0.004	0.02	0.02
40	400	0.0095	0.010	0.273	0.000	0.000	0.124	0.008	0.004	0.02	0.02
41	410	0.0133	0.014	0.288	0.000	0.000	0.135	0.011	0.006	0.03	0.03
42	420	0.0133	0.014	0.302	0.000	0.000	0.147	0.011	0.006	0.03	0.03
43	430	0.0133	0.014	0.316	0.000	0.000	0.158	0.012	0.006	0.04	0.03
44	440	0.0180	0.019	0.336	0.000	0.000	0.174	0.016	0.008	0.05	0.04
45	450	0.0180	0.019	0.355	0.000	0.000	0.190	0.016	0.008	0.05	0.05
46	460	0.0416	0.045	0.400	0.001	0.001	0.229	0.038	0.020	0.12	0.07
47	470	0.0992	0.107	0.506	0.012	0.011	0.324	0.095	0.053	0.32	0.17
48	480	0.0270	0.029	0.535	0.017	0.005	0.350	0.026	0.016	0.09	0.20
49	490	0.0180	0.019	0.555	0.021	0.004	0.368	0.018	0.011	0.06	0.12
50	500	0.0134	0.014	0.569	0.024	0.003	0.381	0.013	0.008	0.05	0.08
51	510	0.0134	0.014	0.583	0.027	0.003	0.394	0.013	0.008	0.05	0.06
52	520	0.0134	0.014	0.598	0.030	0.003	0.408	0.013	0.008	0.05	0.05
53	530	0.0088	0.009	0.607	0.032	0.002	0.416	0.009	0.005	0.03	0.05
54	540	0.0088	0.009	0.617	0.034	0.002	0.425	0.009	0.006	0.03	0.04
55	550	0.0088	0.009	0.626	0.037	0.002	0.434	0.009	0.006	0.03	0.03
56	560	0.0088	0.009	0.636	0.039	0.002	0.443	0.009	0.006	0.03	0.03
57	570	0.0088	0.009	0.645	0.042	0.002	0.452	0.009	0.006	0.03	0.03
58	580	0.0088	0.009	0.655	0.044	0.003	0.461	0.009	0.006	0.03	0.03
59	590	0.0088	0.009	0.664	0.047	0.003	0.469	0.009	0.006	0.03	0.03
60	600	0.0088	0.009	0.673	0.049	0.003	0.478	0.009	0.006	0.03	0.03
61	610	0.0088	0.009	0.683	0.052	0.003	0.487	0.009	0.006	0.04	0.03
62	620	0.0088	0.009	0.692	0.055	0.003	0.496	0.009	0.006	0.04	0.04
63	630	0.0088	0.009	0.702	0.058	0.003	0.505	0.009	0.006	0.04	0.04
64	640	0.0088	0.009	0.711	0.060	0.003	0.514	0.009	0.006	0.04	0.04
65	650	0.0072	0.008	0.719	0.063	0.002	0.521	0.007	0.005	0.03	0.03
66	660	0.0072	0.008	0.727	0.065	0.002	0.529	0.007	0.005	0.03	0.03
67	670	0.0072	0.008	0.735	0.068	0.002	0.536	0.007	0.005	0.03	0.03
68	680	0.0072	0.008	0.742	0.070	0.003	0.543	0.007	0.005	0.03	0.03
69	690	0.0072	0.008	0.750	0.073	0.003	0.551	0.007	0.005	0.03	0.03
70	700	0.0072	0.008	0.758	0.076	0.003	0.558	0.007	0.005	0.03	0.03

Table A8. SBUH Hydrograph Values for Developed Site Condition (Using SEATTLE-Modified SCS Type 1A) (continued)

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
71	710	0.0072	0.008	0.766	0.078	0.003	0.565	0.007	0.005	0.03	0.03
72	720	0.0072	0.008	0.773	0.081	0.003	0.573	0.007	0.005	0.03	0.03
73	730	0.0072	0.008	0.781	0.084	0.003	0.580	0.007	0.005	0.03	0.03
74	740	0.0072	0.008	0.789	0.086	0.003	0.588	0.007	0.005	0.03	0.03
75	750	0.0072	0.008	0.796	0.089	0.003	0.595	0.007	0.005	0.03	0.03
76	760	0.0072	0.008	0.804	0.092	0.003	0.602	0.007	0.005	0.03	0.03
77	770	0.0057	0.006	0.810	0.094	0.002	0.608	0.006	0.004	0.02	0.03
78	780	0.0057	0.006	0.816	0.096	0.002	0.614	0.006	0.004	0.02	0.03
79	790	0.0057	0.006	0.823	0.099	0.002	0.620	0.006	0.004	0.02	0.03
80	800	0.0057	0.006	0.829	0.101	0.002	0.626	0.006	0.004	0.02	0.02
81	810	0.0057	0.006	0.835	0.103	0.002	0.632	0.006	0.004	0.02	0.02
82	820	0.0057	0.006	0.841	0.106	0.002	0.638	0.006	0.004	0.02	0.02
83	830	0.0057	0.006	0.847	0.108	0.002	0.643	0.006	0.004	0.02	0.02
84	840	0.0057	0.006	0.853	0.111	0.002	0.649	0.006	0.004	0.03	0.02
85	850	0.0057	0.006	0.859	0.113	0.002	0.655	0.006	0.004	0.03	0.03
86	860	0.0057	0.006	0.865	0.115	0.002	0.661	0.006	0.004	0.03	0.03
87	870	0.0057	0.006	0.872	0.118	0.002	0.667	0.006	0.004	0.03	0.03
88	880	0.0057	0.006	0.878	0.120	0.002	0.673	0.006	0.004	0.03	0.03
89	890	0.0050	0.005	0.883	0.122	0.002	0.678	0.005	0.004	0.02	0.02
90	900	0.0050	0.005	0.888	0.125	0.002	0.683	0.005	0.004	0.02	0.02
91	910	0.0050	0.005	0.894	0.127	0.002	0.688	0.005	0.004	0.02	0.02
92	920	0.0050	0.005	0.899	0.129	0.002	0.694	0.005	0.004	0.02	0.02
93	930	0.0050	0.005	0.905	0.131	0.002	0.699	0.005	0.004	0.02	0.02
94	940	0.0050	0.005	0.910	0.134	0.002	0.704	0.005	0.004	0.02	0.02
95	950	0.0050	0.005	0.915	0.136	0.002	0.709	0.005	0.004	0.02	0.02
96	960	0.0050	0.005	0.921	0.138	0.002	0.714	0.005	0.004	0.02	0.02
97	970	0.0050	0.005	0.926	0.141	0.002	0.719	0.005	0.004	0.02	0.02
98	980	0.0050	0.005	0.931	0.143	0.002	0.725	0.005	0.004	0.02	0.02
99	990	0.0050	0.005	0.937	0.145	0.002	0.730	0.005	0.004	0.02	0.02
100	1000	0.0050	0.005	0.942	0.148	0.002	0.735	0.005	0.004	0.02	0.02
101	1010	0.0040	0.004	0.947	0.149	0.002	0.739	0.004	0.003	0.02	0.02
102	1020	0.0040	0.004	0.951	0.151	0.002	0.743	0.004	0.003	0.02	0.02
103	1030	0.0040	0.004	0.955	0.153	0.002	0.747	0.004	0.003	0.02	0.02
104	1040	0.0040	0.004	0.959	0.155	0.002	0.752	0.004	0.003	0.02	0.02
105	1050	0.0040	0.004	0.964	0.157	0.002	0.756	0.004	0.003	0.02	0.02
106	1060	0.0040	0.004	0.968	0.159	0.002	0.760	0.004	0.003	0.02	0.02
107	1070	0.0040	0.004	0.972	0.161	0.002	0.764	0.004	0.003	0.02	0.02
108	1080	0.0040	0.004	0.977	0.163	0.002	0.768	0.004	0.003	0.02	0.02
109	1090	0.0040	0.004	0.981	0.165	0.002	0.772	0.004	0.003	0.02	0.02
110	1100	0.0040	0.004	0.985	0.167	0.002	0.777	0.004	0.003	0.02	0.02
111	1110	0.0040	0.004	0.990	0.169	0.002	0.781	0.004	0.003	0.02	0.02
112	1120	0.0040	0.004	0.994	0.171	0.002	0.785	0.004	0.003	0.02	0.02

Table A8. SBUH Hydrograph Values for Developed Site Condition (Using SEATTLE-Modified SCS Type 1A) (continued)

Time Increment	Time (min)	Rainfall Distrib. (Fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Pervious Accum. Runoff (inches)	Pervious Area Incr. Runoff (inches)	Impervious Accum. Runoff (inches)	Impervious Area Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
113	1130	0.0040	0.004	0.998	0.173	0.002	0.789	0.004	0.003	0.02	0.02
114	1140	0.0040	0.004	1.002	0.175	0.002	0.793	0.004	0.003	0.02	0.02
115	1150	0.0040	0.004	1.007	0.177	0.002	0.797	0.004	0.003	0.02	0.02
116	1160	0.0040	0.004	1.011	0.179	0.002	0.802	0.004	0.003	0.02	0.02
117	1170	0.0040	0.004	1.015	0.181	0.002	0.806	0.004	0.003	0.02	0.02
118	1180	0.0040	0.004	1.020	0.183	0.002	0.810	0.004	0.003	0.02	0.02
119	1190	0.0040	0.004	1.024	0.185	0.002	0.814	0.004	0.003	0.02	0.02
120	1200	0.0040	0.004	1.028	0.187	0.002	0.818	0.004	0.003	0.02	0.02
121	1210	0.0032	0.003	1.032	0.189	0.002	0.822	0.003	0.002	0.02	0.02
122	1220	0.0032	0.003	1.035	0.190	0.002	0.825	0.003	0.002	0.02	0.02
123	1230	0.0032	0.003	1.039	0.192	0.002	0.828	0.003	0.002	0.02	0.02
124	1240	0.0032	0.003	1.042	0.193	0.002	0.832	0.003	0.002	0.02	0.02
125	1250	0.0032	0.003	1.045	0.195	0.002	0.835	0.003	0.003	0.02	0.02
126	1260	0.0032	0.003	1.049	0.197	0.002	0.838	0.003	0.003	0.02	0.02
127	1270	0.0032	0.003	1.052	0.199	0.002	0.842	0.003	0.003	0.02	0.02
128	1280	0.0032	0.003	1.056	0.200	0.002	0.845	0.003	0.003	0.02	0.02
129	1290	0.0016	0.002	1.057	0.201	0.001	0.847	0.002	0.001	0.01	0.01
130	1300	0.0016	0.002	1.059	0.202	0.001	0.848	0.002	0.001	0.01	0.01
131	1310	0.0016	0.002	1.061	0.203	0.001	0.850	0.002	0.001	0.01	0.01
132	1320	0.0016	0.002	1.063	0.204	0.001	0.852	0.002	0.001	0.01	0.01
133	1330	0.0016	0.002	1.064	0.204	0.001	0.853	0.002	0.001	0.01	0.01
134	1340	0.0016	0.002	1.066	0.205	0.001	0.855	0.002	0.001	0.01	0.01
135	1350	0.0016	0.002	1.068	0.206	0.001	0.857	0.002	0.001	0.01	0.01
136	1360	0.0016	0.002	1.070	0.207	0.001	0.858	0.002	0.001	0.01	0.01
137	1370	0.0016	0.002	1.071	0.208	0.001	0.860	0.002	0.001	0.01	0.01
138	1380	0.0016	0.002	1.073	0.209	0.001	0.862	0.002	0.001	0.01	0.01
139	1390	0.0003	0.000	1.073	0.209	0.000	0.862	0.000	0.000	0.00	0.01
140	1400	0.0003	0.000	1.074	0.209	0.000	0.862	0.000	0.000	0.00	0.00
141	1410	0.0003	0.000	1.074	0.209	0.000	0.863	0.000	0.000	0.00	0.00
142	1420	0.0003	0.000	1.074	0.209	0.000	0.863	0.000	0.000	0.00	0.00
143	1430	0.0003	0.000	1.075	0.209	0.000	0.863	0.000	0.000	0.00	0.00
144	1440	0.0003	0.000	1.075	0.210	0.000	0.864	0.000	0.000	0.00	0.00
	SUM	**1.000**	**1.075**	**93.333**	**12.724**	**0.210**	**68.996**	**0.864**	**0.537**	**3.247**	**3.245**

APPENDIX B

FACILITY MAINTENANCE REQUIREMENTS

City of Seattle
Stormwater Treatment Technical
Requirements Manual

Effective January 1, 2001

Introduction

This appendix outlines inspection, maintenance, and recordkeeping requirements for stormwater detention and treatment systems. In addition, this appendix includes basic information about the common types of drainage systems used to detain and treat urban runoff, how they function, and how well they perform in removing stormwater pollutants. The types of drainage systems covered in this appendix include:

- Catch basins, maintenance holes, and storm drain inlets
- Vaults, tanks, and pipes
- Oil/water separators
- Media filters
- Biofilters (swales and filter strips)
- Infiltration trenches
- Ponds and constructed wetlands

The appendix is separated into two sections:

Part I: Inspection and Maintenance Requirements

The first section describes each type of drainage system and lists the inspection and maintenance requirements for each system. The inspection and maintenance requirements include information about what features to inspect at each facility, when and how often these systems should be inspected, and how to identify specific defects that warrant corrective action. Corrective actions are described that should be taken to maintain system performance.

Part II: Inspection Checklists

The second section contains checklists to assist owners of private systems in conducting inspections and to aid in inspection documentation. Recordkeeping is an important component of any maintenance program. It is necessary to ensure that inspections and maintenance operations are completed as scheduled and also to track the level of maintenance required at individual facilities and structures.

The checklists contain a list of features to inspect, the required inspection frequency, and how to identify items that warrant corrective action. Private owners and inspectors should use these checklists to record what structures and features have been inspected, as well as to identify and comment on specific problems discovered during the inspection. Inspect the facilities according to the frequencies shown on the checklists. Some facility items need to be inspected twice during the wet season, while other items must be inspected only once each year during the dry season. If the condition of any of the facilities triggers a requirement for maintenance, then make the necessary repairs as described on the checklist. Maintain the completed checklists on file to document that the necessary inspections and maintenance have been completed. City surface water quality inspectors will review these records when checking private systems to see that they are being adequately maintained.

Part I: Inspection and Maintenance Requirements

Catch Basins, Maintenance Holes, and Stormdrain Inlets

Grated and curb-inlet type catch basins are designed to collect and direct runoff into the storm drainage system, as well as to trap debris and litter present in roadway runoff. Unlike maintenance holes and inlets, catch basins contain a sump at the bottom of the structure to collect sediment and other debris. The purpose of the sump is to prevent the downstream pipes from becoming clogged and to prevent sediment and debris from being discharged into receiving waters. In addition, the outlet pipe on catch basins in Seattle is typically installed with a downturned elbow or tee to trap floatable material. Storm drain inlets and maintenance holes which do not contain sumps are not effective in removing pollutants from stormwater.

Pollutant Removal Efficiency

Catch basins are capable of removing larger size sediment particles (e.g., sand and gravel) and debris (e.g., pine needles, leaves, and litter). Typical removal pollutant efficiencies for catch basins are provided below:

Pollutant	Removal Efficiency (percent)
Total suspended solids	10-25
Total phosphorus	5-10
Total nitrogen	5-10
Lead	10-25
Zinc	5-10
Hydrocarbons	0

Inspection and Maintenance Requirements

See the following table.

Inspection and Maintenance Requirements for Owners of Private Systems: Catch Basins, Maintenance Holes, and Inlets

Catch Basin Components	Inspection Frequency[1]			
Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
Cleaning				
Trash, debris, sediment, vegetation	✓	✓	Accumulated material within 18 inches of the bottom of the lowest pipe entering or exiting the structure.	Remove/dispose
	✓	✓	Sediment visible in inlet/outlet pipes.	Rod lines
	✓	✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes
	✓	✓	Vegetation/debris on inlet grate.	Clean and dispose material
Pollution	✓	✓	Chemicals (solvents, gas, diesel, paint, natural gas) present	Identify and control source.
Structure				
Frame and/or top slab			Corner extends more than 0.75 inch past curb face or street surface (where applicable)	Repair so frame even with curb
		✓	Holes greater than 2" or cracks greater than 0.5" in top slab	Repair to water tight condition
		✓	Frame not flush with top slab (separation >0.75")	Repair
CB structure		✓	Cracks wider than 0.5" and longer than □ feet, missing bricks, or any evidence of water leakage, bricks missing	Repair
		✓	Cracks wider than 0.5" and longer than 1 foot at pipe inlet/outlet	Repair
Cover/grate		✓	Cover/grate missing, damaged, or only partially in place	Repair/replace
		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace
	✓	✓	Buried	Excavate
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

2. Vaults, tanks, and pipes

Vaults, tanks, and pipes are underground storage facilities that can be designed as dry systems (i.e., detention for flow control), wet systems for water quality treatment, or as combined systems that provide both flow and water quality control. Underground facilities are generally used to manage storm water from smaller sites (e.g., less than 5 acres). Vaults are typically constructed of reinforced concrete, while tanks and pipes are usually made of corrugated metal or plastic pipe.

Dry vaults/tanks. In Seattle, dry vaults/tanks (i.e., detention) are most common. Detention systems are designed primarily to control the rate of runoff from developed sites. Runoff enters the vault or tank and is temporarily stored as water is slowly released through a small orifice to the downstream drainage system. Detention storage is often referred to as “live” storage. Controlling peak discharge rates from developed sites reduces stream bank erosion and minimizes flooding in downstream areas. Detention vaults/tanks are designed to drain completely dry following storm events. Although not specifically designed to provide water quality treatment, these systems can also remove some pollutants if the storage volume is large enough to adequately detain incoming runoff. Typically a storage time of 24 hours or more is needed for a detention vault/tank to provide any significant amount of pollutant removal. Removal occurs primarily via sedimentation as suspended solids and particulate-bound pollutants settle out in the vault/tank.

Wet vaults/tanks. Wet vaults/tanks contain a permanent pool (i.e., wet pool) that functions as an energy dissipater, slowing the velocity of incoming storm water and allowing suspended sediment to settle. The permanent pool volume is generally referred to as “dead” storage. Wet vaults/tanks typically provide no live storage for flow control purposes and function only as water treatment devices.

Combined systems. Combined systems simply incorporate the live storage of a dry vault/tank with the dead storage (i.e., wet pool) of a wet vault/tank into a single facility. Consequently, these facilities provide both flow control and water quality treatment. Pollutant removal mechanisms in a combined system are similar to those described above under water quality ponds.

Pollutant Removal Efficiency. Pollutant removal in vaults, tanks, and pipes occurs primarily via sedimentation. Opportunities for biological treatment are negligible in these below ground structures. In addition, it should be pointed out that tank/pipe systems constructed of galvanized pipe are likely a source of zinc to the downstream system. Vaults, tanks, and ponds remove suspended sediment and particulate-bound pollutants. Typical removal efficiencies are provided below:

	Pollutant Removal Efficiency(percent)	
Pollutant	Dry Vault[a]	Wet Vault[a]
Total suspended solids	10-60	40-75
Total phosphorus	10-25	20-60
Total nitrogen	10-15	10-75
Lead	60-80	10-80
Zinc	25-50	10-80
Hydrocarbons	40-60	

a. Vault removal efficiencies estimated at 85 percent of pond removal efficiencies.

Inspection and Maintenance Requirements

See the following table.

Inspection and Maintenance Requirements for Owners of Private Systems: Vaults, Tanks, and Detention Pipes

	Inspection Frequency[1]			
Vault Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
General				
Trash/debris	✓	✓	More than 1 ft^3	Remove/dispose
Sediment		✓	Accumulated sediment in vault/tank exceeds 6 inches.	Remove/dispose
Pollution *(check for noticeable sheen or unusual odor)*		✓	Any visible accumulation of oil, gas, or other contaminant.	Remove/dispose
Vault/Tank Structure				
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace
Concrete *(inspect when vault cleaned)*			Riser, concrete walls, or joints cracked or leaking. Bricks missing. Cracks greater than 0.5 inches wide.	Repair
Maintenance holes		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace
		✓	Buried	Excavate
Inlet grates		✓	Cracked or broken grate	Replace
Baffle(s)		✓	Corroded, cracked, or warped.	Repair/replace
Air vents		✓	Plugged or blocked with debris	Clean
Control Structure				
Shear gate (*exercise full open/close and inspect)*			Gate cannot be operated by 1 person	Lubricate, repair, or replace
		✓	Gate rusted, not watertight, or missing	Repair/replace
		✓	Chain or pull rod missing	Replace
		✓	Not plumb within 10%	Repair
		✓	Connection to outlet pipe rusted or leaking	Repair/replace
Orifice plates *(inspect when vault cleaned)*			Bent, rusted, or missing	Replace
Sediment/debris		✓	More than 12 inches of accumulated material.	Clean/remove
Outlet pipe		✓	Submerged or partially submerged	Check for downstream obstruction
Oil absorbent pads		✓	Pads missing or stained over more than 75% of pad area	Remove and replace
Shutoff Valve and/or Maintenance Drain				
Valve exercised		✓	Valve cannot be operated by 1 person. Valve rusted or not watertight.	Repair/replace
Sediment		✓	Vertical distance between sediment and drain pipe is less than 6 inches.	Remove and dispose
Inlet/Outlet				
Trash rack	✓	✓	Trash or other debris present on trash rack.	Clean and dispose trash
		✓	Bar screen damaged or missing	Replace
Pipes			Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes
Receiving water			Erosion damage along banks	Regrade/armour below outlet

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Oil/Water Separators

Oil/water separators are used to treat storm water runoff from high use developments that generate relatively large quantities of oil and grease (e.g., shopping centers, roadways, and parking lots). There are three types of oil/water separators: the conventional gravity API (American Petroleum Institute) separator, coalescing plate separators (CPS), and floatable material separators (FMS).

The conventional gravity API separator consists of a large vault equipped with baffles to prevent oil and other floating debris from passing through the separator. The baffles extend down vertically from the top of the vault, trapping floatable material within the vault chambers. In addition, a baffle is usually installed on the bottom at the upstream end of the vault to trap suspended sediment. Oil absorbent pads or mechanical skimmers can also be installed in the main chamber to remove separated oil.

Coalescing plate separators are similar to API separators except that a bank of closely spaced, inclined, corrugated plates is inserted into the separator chamber to improve removal efficiency. Consequently, these systems are usually smaller in size than the conventional API separator. The plates are usually constructed of fiberglass, stainless steel, or polypropylene. Because of the closely spaced configuration of the plates, sediment and other debris can easily clog these systems. Therefore, to work effectively, the coalescing plates must be kept clean.

FMS separators are simple containment devices capable of trapping floatable materials. They consist of a vault or manhole structure that is equipped with a downturned elbow on the outlet. These devices are not as effective as CPS and API separators in separating oil; they function primarily for spill containment and as floating debris traps.

Pollutant Removal Efficiency

Oil/water separators are gravity separation devices that function because materials that are lighter than water (e.g., oil, grease, plastic debris) tend to float and can be separated from the water. With respect to oil, these devices are capable of removing free oil, but are not effective in separating oil that has become either chemically or mechanically emulsified or dissolved in water. Performance is largely dependent on the size of oil globules present in the runoff. A conventional API separator is typically designed to remove 150-micron size or larger oil droplets and can achieve approximately 40 percent removal of the total volume of oil present. Coalescing plate separators are usually designed to remove 60-micron size or larger oil droplets and are capable of removing approximately 80 percent of the oil. Typical removal efficiencies for oil/water separators are provided below:

Pollutant	Pollutant Removal Efficiency (percent)
Total suspended solids	10-25
Total phosphorus	5-10
Total nitrogen	5-10
Lead	10-25
Zinc	5-10
Hydrocarbons	40-80

Inspection and Maintenance Requirements

See the following table

Inspection and Maintenance Requirements for Owners of Private Drainage Facilities
Oil/Water Separators

	Inspection Frequency[1]			
Separator Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
General (all types of separators)				
Discharge quality	✓	✓	Oil sheen, unusual color, petroleum odor	Identify/control source
Trash and debris	✓	✓	Trash visible in vault, inlet/outlet pipes	Remove and dispose
Sediment	✓	✓	Depth exceeds 6 inches or space between bottom of inlet baffle and vault floor is less than 50% open, whichever is less	Remove and dispose
Oil absorbent pads	✓	✓	Pads missing or stained over more than 75% of pad area	Remove and replace
Bypass valve (*exercise full open/close and inspect)*			Gate cannot be operated by 1 person	Lubricate, repair, or replace
Inlet/outlet pipe		✓	Pipe rusted or damaged. Leaking at vault penetration or pipe obstructed by sediment/debris.	Repair/replace/clean
		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes
Outlet pipe		✓	Submerged or partially submerged	Check for downstream obstruction
Vault Structure (all types of separators)				
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace
Concrete *(inspect when vault cleaned)*			Riser, concrete walls, or joints cracked or leaking. Bricks missing. Cracks greater than 0.5 inches wide.	Repair
Maintenance holes		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace
		✓	Buried	Excavate
Inlet grates		✓	Cracked or broken grate	Replace
Baffle(s)		✓	Corroded, cracked, or warped, or otherwise structurally unsound.	Repair/replace
Coalescing plates (CPS Separators)				
Sediment	✓	✓	Depth exceeds 6 inches or visible clogging of plates	Clean
Plates		✓	Brittle, cracked, or deformed	Replace
Spill Control Separators				
Tee section		✓	Missing	Replace
		✓	Loose, not firmly attached to manhole wall	Repair
		✓	Not plumb within 10%	Repair

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Media Filters

Filters are a relatively new technology for treating stormwater runoff. These systems involve passing runoff through a filtration media to remove pollutants. After treatment in the filter, runoff is collected in an underdrain system and discharged to the public drainage control system. Structures may be constructed above ground in open ponds or below ground in vaults. For below ground filters, the filter media is often contained in canisters rather than being placed loose in the structure. Various media have been used, including sand, leaf compost, perlite, zeolite, and peat moss. Sand and leaf compost filters are the most common type of media used. Leaf compost media is a proprietary product. As a result, these filters and replacement media must be purchased from the manufacturer. Other media such as perlite and zeolite are being developed and tested for stormwater applications, but have not been commonly used in the Puget Sound region.

Filters require special care to prevent the filter surface from becoming clogged. Once a filter begins to clog, the hydraulic capacity drops dramatically, causing the filter to go into overflow stage much more frequently than usual. As a result, treatment performance is severely reduced. Therefore, pretreatment systems such as biofilters, wet ponds, or wet vaults are often installed immediately upstream of filtration systems to prolong the life of the filter media.

Pollutant Removal Efficiency

Filters are highly effective in removing suspended solids and particulate-bound pollutants. In addition, depending on the media used, these systems may also remove some dissolved pollutants. For example, leaf compost filters are effective in removing dissolved metals. However, because of its high organic content, compost media is actually a source of nutrients, particularly phosphorus. Consequently, compost media should not be used on sites where nutrient control is a concern. Various other amendments have been added to filtration media to improve the removal of dissolved pollutants, including iron and peat moss. Removal of dissolved pollutants typically occurs via chemical reactions within the media—chemical adsorption and exchange reactions are the most common mechanisms. Typical pollutant removal efficiencies for filtration devices are listed below:

Pollutant	Pollutant Removal Efficiency (percent)
Total suspended solids	60-90
Total phosphorus	0-80
Total nitrogen	20-40
Lead	40-80
Zinc	40-80
Hydrocarbons	

Inspection and Maintenance Requirements

See the following table.

Inspection and Maintenance Requirements for Owners of Private Systems: Media Filters

	Inspection Frequency[1]			
Filter Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
Filter Media/Surface				
Trash/debris	✓	✓	More than 1 ft^3	Remove/dispose
Sediment	✓	✓	Filter surface: >75% coverage of sediment on top of media	Scrape or rototill
Filtration rate[2]	✓		Less than approximately 1 in/hr. averaged over a four-hour period	Scrape, rototill, or replace media
Pollution *(check for noticeable sheen or unusual odor)*	✓	✓	Any visible accumulation of oil, gas, or other contaminant	Remove/dispose
Erosion/scouring		✓	Rills/gullies more than 2 inches deep or otherwise uneven surface	Regrade filter surface
Flow/level spreader		✓	Erosion damage at outlet greater than 2 inches deep and 6 inches wide	Restore filter surface, install erosion controls as needed.
		✓	Short-circuiting (uneven ponding over filter surface)	Regrade filter surface, repair level spreader
Vault Structure (underground systems)				
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace
Concrete *(inspect when vault cleaned)*		✓	Riser, concrete walls, or joints cracked or leaking. Bricks missing. Cracks greater than 0.5 inches wide.	Repair
Maintenance holes		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace
		✓	Buried	Excavate
Baffle(s)		✓	Corroded, cracked, or warped.	Repair/replace
Air vents		✓	Plugged or blocked with debris	Clean
Filter Basin (above ground systems)				
Noxious weeds		✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings
Grass/ground cover		✓	Residential area: mow when grass height reaches 18". In other areas, match adjacent ground cover/terrain as long as there is no interference with facility function.	Mow to 2-inch height. Remove cuttings and dispose
Fence		✓	Damage to gate/fence, posts out of plumb, or rails bent more than 6 inches.	Repair/replace
		✓	Brush/weeds along fenceline	Remove brush to within 3 feet of fence
		✓	Erosion/settlement causing opening under the fence greater than 4 inches and 12-18 inches wide or openings along fenceline greater than 8-inch diameter.	Repair
Dike/berm/embankment		✓	Settlement greater than 4 inches (relative to undisturbed sections of berm)	Restore to design height

	Inspection Frequency[1]			
Filter Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
		✓	Downstream face of berm or embankment wet, seeps or leaks evident	Plug holes. Contact geotechnical engineer ASAP
		✓	Any evidence of rodent holes or water piping around holes if facility acts as dam or berm	Eradicate rodents/repair holes (fill and compact)
		✓	Erosion (gullies/rills) greater than 2 inches around inlets, outlet, and along side slopes. Note evidence of leakage through embankment.	Eliminate source of erosion and stabilize damaged area (regrade, rock, vegetation, erosion control blanket)
Underdrains/Valves				
Valve exercised		✓	Valve cannot be operated by 1 person. Valve rusted or not watertight.	Repair/replace
Sediment		✓	More than 1 inch of sediment in underdrain pipe	Remove and dispose
Inlet/Outlet				
Trash rack	✓	✓	Trash or debris present on trash rack	Clean and dispose trash
		✓	Bar screen damaged or missing	Replace
Pipes		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).
2. Take filter offline. Measure drop in water level over at least 4 hr period. Filtration rate = Drop in water level (in)/time interval (hr).

Biofilters (Swales and Filter Strips)

Two types of biofilters are commonly used in stormwater treatment applications: biofiltration swales and vegetated filter strips. Both are land treatment systems that serve both conveyance and treatment functions. They are designed to remove pollutants by filtering stormwater through vegetation. They are usually planted with grass, however other vegetation such as emergent wetland species can be used depending on site conditions.

Swales are broad, gently sloped channels that are designed to spread storm water flows over a wide, flat-bottomed channel to reduce flow velocity and promote contact with the vegetation. The longitudinal slope of a swale should be greater than 1 percent to convey flow, but not overly steep, to prevent erosion damage and to provide adequate time of contact between the storm water and vegetation. Slopes of between 2 and 4 percent are generally recommended for swales. If the slope is too great, check dams can be installed to slow down the flow.

Filter strips are broad vegetated surfaces that are designed to receive runoff in the form of sheet flow, rather than concentrated channel flow like swales. One disadvantage of filter strips is the difficulty in maintaining sheet flow due to the tendency for rills and channels to form as a result of unevenly distributed flow and excessive flow that stimulates erosion. Filter strips are generally most effective in locations where the contributing area is less than 5 acres and has slopes less than 10 percent.

Pollutant Removal Efficiency

Biofilters are mainly effective in removing suspended sediment and particulate-bound pollutants via filtration and sedimentation. Dense vegetation aids in the filtration process as particulates and associated pollutants adhere to the grass blades as runoff passes through the filter. Sedimentation occurs when runoff is spread across the large filtration area, thus reducing the flow velocity and allowing particles to settle in the filter. To a lesser extent, biofilters can remove dissolved pollutants through biological and chemical mechanisms. Biological removal occurs primarily through plant uptake and microbial degradation. Typical removal efficiencies for biofilters are provided below:

Pollutant	Pollutant Removal Efficiency (percent)
Total suspended solids	40-90
Total phosphorus	5-50
Total nitrogen	10-60
Lead	□0-80
Zinc	10-50
Hydrocarbons	60-90

Inspection and Maintenance Requirements

See the following table.

Inspection and Maintenance Requirements for Owners of Private Systems: Biofiltration Swales and Filter Strips

Swale/Filter Strip	**Inspection Frequency**[1]			
Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
Swale/Filter areas				
Trash/yard waste	✓	✓	More than 1 ft^3	Remove/dispose
Sediment	✓	✓	Accumulated sediment exceeds 4 inches or covers grass, especially within the upper section, near inlet.	Remove/dispose sediment. Restore grass, protect from erosion until vegetation established.
Pollution		✓	Any visible accumulation of oil, gas, or other contaminant.	Remove/dispose
Noxious weeds		✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings
Grass/vegetation		✓	Grass height exceeds 12 inches.	Mow to 4-inch height. Remove and dispose cuttings
		✓	Poor vegetation growth (<75 percent coverage)	Aerate soil, fertilize with 21-3-21 low P fertilizer, and reseed
Flow characteristics		✓	Standing/stagnant water, no visible water movement.	Check for downstream obstruction.
Erosion/scouring		✓	Flow channelized, forming rills/gullies more than 2 inches deep.	Regrade swale bottom, re-install flow spreader, revegetate, protect from erosion until vegetation established.
Flow Spreader				
Sediment	✓	✓	Ports/notches clogged or sediment trap filled.	Remove and dispose
Grade board/baffle	✓	✓	Damaged or not level	Remove and reinstall to level position.

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Infiltration Trenches

Infiltration trenches and other stormwater infiltration systems such as rock pockets and dry wells temporarily store stormwater so that it can gradually seep into the underlying soil and groundwater. Infiltration systems treat stormwater runoff by physically filtering particulates and particulate-bound pollutants as the water moves through the soil. In addition, pollutants can sorb onto the soil particles which aids in removing dissolved pollutants. Microbial degradation of some contaminants can also occur as water infiltrates through the soil.

Infiltration systems can also be used to reduce the rate of runoff from a site by removing the volume of runoff that would otherwise be discharged to the surface drainage system and allowing it to infiltrate into the ground. However, due to the relatively low permeability of soil in many areas of the City of Seattle, infiltration systems have fairly limited applicability in the Seattle area. Infiltration systems in Seattle are typically only useful for fairly small sites where the volume of runoff is low.

Pollutant Removal Efficiency

Infiltration systems can provide effective removal of suspended sediment and particulate-bound pollutants. Typical removal efficiencies are provided below:

Pollutant	Pollutant Removal Efficiency (percent)
Total suspended solids	45-100
Total phosphorus	40-100
Total nitrogen	0-100
Lead	45-100
Zinc	45-100
Hydrocarbons	

Inspection and Maintenance Requirements

See the following table.

Inspection and Maintenance Checklist/Report for Owners of Private Systems: Infiltration Trenches

	Inspection Frequency[1]			
Trench Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
General				
Trash/debris	✓	✓	More than 1 ft^3	Remove/dispose
Pollution *(check for noticeable sheen or unusual odor)*	✓	✓	Any visible accumulation of oil, gas, or other contaminant	Remove/dispose
Noxious weeds	✓	✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings
Drain rock	✓	✓	Water ponds at surface during storm events. Little or no water flows through system	Replace rock material
Roof downspout	✓	✓	Splash pad missing or damaged	Repair/replace
Storage Sump (if present)				
Sediment		✓	Accumulated material within 18 inches of the bottom of the outlet pipe.	Remove/dispose
Maintenance holes		✓	Cannot be opened by one person. Lock missing or damaged	Repair/replace
		✓	Buried	Excavate
Pollution *(check for noticeable sheen or unusual odor)*	✓	✓	Any visible accumulation of oil, gas, or other contaminant	Remove/dispose

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Ponds

Like vaults, ponds are storage facilities that can be designed as detention, water quality, or combined systems, except that ponds are above ground rather than underground facilities. Ponds are not commonly used in Seattle because above ground systems require more land to construct, which is usually not available in a highly urban setting. In addition to physical removal via sedimentation, ponds, particularly wet ponds also provide a suitable environment and adequate hydraulic residence time to promote biological and chemical reactions, which improves their ability to remove pollutants from urban runoff. In addition, aquatic plants that establish in the wet pool can also enhance sedimentation and promote pollutant uptake.

Pollutant Removal Efficiency

Well-maintained ponds can provide effective removal of suspended sediment and particulate-bound pollutants. Typical removal efficiencies for extended detention ponds and water quality ponds are provided below:

	Pollutant Removal Efficiency(percent)	
Pollutant	Dry Pond	Wet Pond
Total suspended solids	10-70	50-90
Total phosphorus	10-30	25-70
Total nitrogen	10-20	10-90
Lead	75-90	10-95
Zinc	30-60	10-95
Hydrocarbons	50-70	

Inspection and Maintenance Requirements

See the following table.

Inspection and Maintenance Requirements for Owners of Private Systems: Ponds and Constructed Wetlands

	Inspection Frequency[1]			
Pond Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
Dry Pond Areas				
Trash/yard waste	✓	✓	More than 1 ft^3	Remove/dispose
Sediment		✓	Accumulated sediment exceeds 1 foot.	Remove/restore
Pollution	✓	✓	Any visible accumulation of oil, gas, or other contaminant.	Remove/dispose
Noxious weeds		✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings
Grass/ground cover				Mow to 2-inch height. Remove cuttings and dispose
Insects		✓	Wasps, hornets interfere with operations	Remove
Tree/brush growth		✓	Growth does not allow maintenance access, interferes with future maintenance activity (e.g., alder), or reduces storage capacity. Otherwise leave alone.	Remove and restore pond bottom
Fence		✓	Damage to gate/fence, posts out of plumb, or rails bent more than 6 inches.	Repair/replace
		✓	Brush/weeds along fenceline	Remove brush to within 3 feet of fence
		✓	Erosion/settlement causing opening under the fence greater than 4 inches and 12-18 inches wide or openings along fenceline greater than 8-inch diameter.	Repair
Embankment and Emergency Spillway				
Spillway		✓	Rock lining down to 1 layer of rock	Add rock to design conditions.
		✓	Brush, tree (alder) growth on spillway.	Remove and dispose
Embankment		✓	Downstream face wet, seeps or leaks evident	Plug holes. Contact geotechnical engineer ASAP
		✓	Any evidence of rodent holes or water piping around holes if facility acts as dam or berm	Eradicate rodents/repair holes (fill and compact)
		✓	Erosion (gullies/rills) greater than 2 inches around inlets, outlet, and along side slopes. Note evidence of leakage through embankment.	Eliminate source of erosion and stabilize damaged area (regrade, rock, vegetation, erosion control blanket)
		✓	Settlement greater than 4 inches (relative to undisturbed sections of berm)	Restore to design height

	Inspection Frequency[1]			
Pond Components	**W**	**A**	**Condition when maintenance required**	**Action Required**
Control Structure				
Shear gate (*exercise full open/close and inspect)*		✓		Lubricate, repair, or replace
Shear gate (cont)		✓	Gate rusted, not watertight, or missing	Repair/replace
		✓	Chain or pull rod missing	Replace
Riser		✓	Loose, not firmly attached to manhole wall	Repair
		✓	Not plumb within 10%	Repair
		✓	Connection to outlet pipe rusted or leaking	Repair/replace
Maintenance hole		✓	Cannot be opened by one person. Lock missing or damaged	Repair/replace
		✓	Buried	Excavate
Orifice plate(s)		✓	Bent, rusted, or missing	Replace
Structural integrity		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace
		✓	Cracks wider than 0.5" and longer than 3 feet, missing bricks, or any evidence of water leakage	Repair
		✓	Lock bolts on maintenance hole cover missing	Replace
		✓	Cracked or broken grate	Replace
Sediment, trash		✓	Accumulated material within 18 inches of the bottom of the outlet pipe.	Remove/dispose
Outlet pipe		✓	Submerged or partially submerged	Check for downstream obstruction
		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes
Permanent Pool (wet ponds)				
Undesirable or excessive vegetation				Remove and replant with sedges, rushes, other wetland plants.
Sediment		✓	Accumulated sediment greater than depth of the sediment zone in forebay (typically 1 foot) plus 6 inches.	Remove, regrade, and replant pond bottom.
Shutoff Valve and/or Maintenance Drain				
Valve exercised		✓	Valve cannot be operated by 1 person. Valve rusted or not watertight.	Repair/replace
Sediment		✓	Vertical distance between sediment and drain pipe is less than 6 inches.	Remove and dispose
Pond Outlet				
Trash rack	✓	✓	Trash or other debris present on trash rack.	Clean and dispose trash
		✓	Bar screen damaged or missing	Replace
Inlet/outlet pipes			Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes
Receiving water	✓	✓	Erosion damage along banks	Regrade/armour below outlet

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Part II: Inspection Checklists

Inspection and Maintenance Checklist/Report for Owners of Private Systems:
Catch Basins, Maintenance Holes, and Inlets

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

	Inspection Frequency.[1]						
Catch Basin Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Cleaning							
Trash, debris, sediment, vegetation	✓	✓	Accumulated material within 18 inches of the bottom of the lowest pipe entering or exiting the structure.	Remove/dispose			
	✓	✓	Sediment visible in inlet/outlet pipes.	Rod lines			
	✓	✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes			
	✓	✓	Vegetation/debris on inlet grate.	Clean and dispose material			
Pollution	✓	✓	Chemicals (solvents, gas, diesel, paint, natural gas) present	Identify and control source.			
Structure							
Frame and/or top slab			Corner extends more than 0.75 inch past curb face or street surface (where applicable)	Repair so frame even with curb			
		✓	Holes greater than 2" or cracks greater than 0.5" in top slab	Repair to water tight condition			
		✓	Frame not flush with top slab (separation >0.75")	Repair			
CB structure		✓	Cracks wider than 0.5" and longer than 3 feet, missing bricks, or any evidence of water leakage, bricks missing	Repair			
		✓	Cracks wider than 0.5" and longer than 1 foot at pipe inlet/outlet	Repair			

	Inspection Frequency.[1]						
Catch Basin Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Cover/grate		✓	Cover/grate missing, damaged, or only partially in place	Repair/replace			
		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace			
	✓	✓	Buried	Excavate			
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Inspection and Maintenance Checklist/Report for Owners of Private Systems: Vaults, Tanks, and Detention Pipes

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

	Inspection Frequency[1]						
Vault Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Trash/debris	✓	✓	More than 1 ft^3	Remove/dispose			
Sediment		✓	Accumulated sediment in vault/tank exceeds 6 inches.	Remove/dispose			
Pollution *(check for noticeable sheen or unusual odor)*		✓	Any visible accumulation of oil, gas, or other contaminant.	Remove/dispose			
Vault/Tank Structure							
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace			
Concrete *(inspect when vault cleaned)*		✓	Riser, concrete walls, or joints cracked or leaking. Bricks missing. Cracks greater than 0.5 inches wide.	Repair			
Maintenance holes		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace			
		✓	Buried	Excavate			
Inlet grates		✓	Cracked or broken grate	Replace			
Baffle(s)		✓	Corroded, cracked, or warped.	Repair/replace			
Air vents		✓	Plugged or blocked with debris	Clean			
Control Structure							
Shear gate (*exercise full open/close and inspect)*		✓	Gate cannot be operated by 1 person	Lubricate, repair, or replace			
		✓	Gate rusted, not watertight, or missing	Repair/replace			
		✓	Chain or pull rod missing	Replace			

	Inspection Frequency[1]						
Vault Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
		✓	Not plumb within 10%	Repair			
		✓	Connection to outlet pipe rusted or leaking	Repair/replace			
Orifice plates *(inspect when vault cleaned)*		✓	Bent, rusted, or missing	Replace			
Sediment/debris		✓	More than 12 inches of accumulated material.	Clean/remove			
Outlet pipe		✓	Submerged or partially submerged	Check for downstream obstruction			
Oil absorbent pads		✓	Pads missing or stained over more than 75% of pad area	Remove and replace			
Shutoff Valve and/or Maintenance Drain							
Valve exercised		✓	Valve cannot be operated by 1 person. Valve rusted or not watertight.	Repair/replace			
Sediment		✓	Vertical distance between sediment and drain pipe is less than 6 inches.	Remove and dispose			
Inlet/Outlet							
Trash rack	✓	✓	Trash or other debris present on trash rack.	Clean and dispose trash			
		✓	Bar screen damaged or missing	Replace			
Pipes		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes			
Receiving water	✓	✓	Erosion damage along banks	Regrade/armour below outlet			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Inspection and Maintenance Checklist/Report for Owners of Private Drainage Facilities
Oil/Water Separators

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

	Inspection Frequency[1]						
Separator Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
General (all types of separators)							
Discharge quality	✓	✓	Oil sheen, unusual color, petroleum odor	Identify/control source			
Trash and debris	✓	✓	Trash visible in vault, inlet/outlet pipes	Remove and dispose			
Sediment	✓	✓	Depth exceeds 6 inches or space between bottom of inlet baffle and vault floor is less than 50% open, whichever is less	Remove and dispose			
Oil absorbent pads	✓	✓	Pads missing or stained over more than 75% of pad area	Remove and replace			
Bypass valve (*exercise full open/close and inspect)*			Gate cannot be operated by 1 person	Lubricate, repair, or replace			
Inlet/outlet pipe		✓	Pipe rusted or damaged. Leaking at vault penetration or pipe obstructed by sediment/debris.	Repair/replace/clean			
		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes			
Outlet pipe		✓	Submerged or partially submerged	Check for downstream obstruction			
Vault Structure (all types of separators)							
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace			

	Inspection Frequency[1]						
Separator Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Concrete *(inspect when vault cleaned)*		✓	Riser, concrete walls, or joints cracked or leaking. Bricks missing. Cracks greater than 0.5 inches wide.	Repair			
Maintenance holes		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace			
		✓	Buried	Excavate			
Inlet grates		✓	Cracked or broken grate	Replace			
Baffle(s)		✓	Corroded, cracked, or warped, or otherwise structurally unsound.	Repair/replace			
Coalescing plates (CPS Separators)							
Sediment	✓	✓	Depth exceeds 6 inches or visible clogging of plates	Clean			
Plates		✓	Brittle, cracked, or deformed	Replace			
Spill Control Separators							
Tee section		✓	Missing	Replace			
		✓	Loose, not firmly attached to manhole wall	Repair			
		✓	Not plumb within 10%	Repair			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Inspection and Maintenance Checklist/Report for Owners of Private Systems: Media Filters

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

Filter Components	Inspection Frequency[1] W	A	Condition when maintenance required	Action Required	Satisfactory	Unsatisfactory	Comments
Filter Media/Surface							
Trash/debris	✓	✓	More than 1 ft^3	Remove/dispose			
Sediment	✓	✓	Filter surface: >75% coverage of sediment on top of media	Scrape or rototill			
Filtration rate[2]	✓		Less than approximately 1 in/hr. over a four hour period	Scrape, rototill, or replace media			
Pollution (check for noticeable sheen or unusual odor)	✓	✓	Any visible accumulation of oil, gas, or other contaminant	Remove/dispose			
Erosion/scouring		✓	Rills/gullies more than 2 inches deep or otherwise uneven surface	Regrade filter surface			
Flow/level spreader		✓	Erosion damage at outlet greater than 2 inches deep and 6 inches wide	Restore filter surface, install erosion controls as needed.			
		✓	Short-circuiting (uneven ponding over filter surface)	Regrade filter surface, repair level spreader			
Vault Structure (underground systems)							
Ladder		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace			
Concrete (inspect when vault cleaned)		✓	Riser, concrete walls, or joints cracked or leaking. Bricks missing. Cracks greater than 0.5 inches wide.	Repair			

	Inspection Frequency[1]						
Filter Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Maintenance hole covers		✓	Cannot be opened by one person. Locking bolts missing or damaged	Repair/replace			
		✓	Buried	Excavate			
Baffle(s)		✓	Corroded, cracked, or warped.	Repair/replace			
Air vents		✓	Plugged or blocked with debris	Clean			
Filter Basin (above ground systems)							
Noxious weeds		✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings			
Grass/ground cover		✓	Residential area: mow when grass height reaches 18". In other areas, match adjacent ground cover/terrain as long as there is no interference with facility function.	Mow to 2-inch height. Remove cuttings and dispose			
Fence		✓	Damage to gate/fence, posts out of plumb, or rails bent more than 6 inches.	Repair/replace			
		✓	Brush/weeds along fenceline	Remove brush to within 3 feet of fence			
		✓	Erosion/settlement causing opening under the fence greater than 4 inches and 12-18 inches wide or openings along fenceline greater than 8-inch diameter.	Repair			
Dike/berm/ embankment		✓	Settlement greater than 4 inches (relative to undisturbed sections of berm)	Restore to design height			
		✓	Downstream face of berm or embankment wet, seeps or leaks evident	Plug holes. Contact geotechnical engineer ASAP			
		✓	Any evidence of rodent holes or water piping around holes if facility acts as dam or berm	Eradicate rodents/repair holes (fill and compact)			
		✓	Erosion (gullies/rills) greater than 2 inches around inlets, outlet, and along side slopes. Note evidence of leakage through embankment.	Eliminate source of erosion and stabilize damaged area (regrade, rock, vegetation, erosion control blanket)			

Filter Components	Inspection Frequency[1] W	A	Condition when maintenance required	Action Required	Satisfactory	Unsatisfactory	Comments
Underdrains/Valves							
Valve exercised		✓	Valve cannot be operated by 1 person. Valve rusted or not watertight.	Repair/replace			
Sediment		✓	More than 1 inch of sediment in underdrain pipe	Remove and dispose			
Inlet/Outlet							
Trash rack	✓	✓	Trash or debris present on trash rack	Clean and dispose trash			
		✓	Bar screen damaged or missing	Replace			
Pipes		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).
2. Take filter offline. Measure drop in water level over at least 4 hr period. Filtration rate = Drop in water level (in)/time interval (hr).

Inspection and Maintenance Checklist/Report for Owners of Private Systems:
Biofiltration Swales and Filter Strips

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

	Inspection Frequency[1]						
Swale/Filter StripComponents	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Swale/Filter areas							
Trash/yard waste	✓	✓	More than 1 ft^3	Remove/dispose			
Sediment	✓	✓	Accumulated sediment exceeds 4 inches or covers grass, especially within the upper section, near inlet.	Remove/dispose sediment. Restore grass, protect from erosion until vegetation established.			
Pollution		✓	Any visible accumulation of oil, gas, or other contaminant.	Remove/dispose			
Noxious weeds		✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings			
Grass/vegetation		✓	Grass height exceeds 12 inches.	Mow to 4-inch height. Remove and dispose cuttings			
		✓	Poor vegetation growth (<75 percent coverage)	Aerate soil, fertilize with 21-3-21 low P fertilizer, and reseed			
Flow characteristics		✓	Standing/stagnant water, no visible water movement.	Check for downstream obstruction.			
Erosion/scouring		✓	Flow channelized, forming rills/gullies more than 2 inches deep.	Regrade swale bottom, re-install flow spreader, revegetate, protect from erosion until vegetation established.			

	Inspection Frequency[1]						
Swale/Filter StripComponents	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
Flow Spreader							
Sediment	✓	✓	Ports/notches clogged or sediment trap filled.	Remove and dispose			
Grade board/baffle	✓	✓	Damaged or not level	Remove and reinstall to level position.			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Inspection and Maintenance Checklist/Report for Owners of Private Systems: Infiltration Trenches

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

	Inspection Frequency[1]						
Trench Components	**W**	**A**	**Condition when maintenance required**	**Action Required**	**Satisfactory**	**Unsatisfactory**	**Comments**
General							
Trash/debris	✓	✓	More than 1 ft^3	Remove/dispose			
Pollution *(check for noticeable sheen or unusual odor)*	✓	✓	Any visible accumulation of oil, gas, or other contaminant	Remove/dispose			
Noxious weeds	✓	✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings			
Drain rock	✓	✓	Water ponds at surface during storm events. Little or no water flows through system	Replace rock material			
Roof downspout	✓	✓	Splash pad missing or damaged	Repair/replace			
Storage Sump (if present)							
Sediment		✓	Accumulated material within 18 inches of the bottom of the outlet pipe.	Remove/dispose			
Maintenance holes		✓	Cannot be opened by one person. Lock missing or damaged	Repair/replace			
		✓	Buried	Excavate			
Pollution *(check for noticeable sheen or unusual odor)*	✓	✓	Any visible accumulation of oil, gas, or other contaminant	Remove/dispose			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).

Inspection and Maintenance Checklist/Report for Owners of Private Systems:
Ponds and Constructed Wetlands

Date: ________________ Time:____________ Type of Inspection (*circle one*): Wet Annual

Site Name/Location:____

Inspector:____

	Inspection Frequency[1]						
Pond Components	W	A	Condition when maintenance required	Action Required	Satisfactory	Unsatisfactory	Comments
Dry Pond Areas							
Trash/yard waste	✓	✓	More than 1 ft^3	Remove/dispose			
Sediment		✓	Accumulated sediment exceeds 1 foot.	Remove/restore			
Pollution	✓	✓	Any visible accumulation of oil, gas, or other contaminant.	Remove/dispose			
Noxious weeds		✓	Any nuisance or noxious veg. (morning glory, English ivy, reed canary grass, Japanese knotweed, purple loosestrife, blackberry, Scotch broom, tansy, poison oak, stinging nettles, devils club).	Remove and dispose cuttings			
Grass/ground cover		✓	Residential area: mow when grass height reaches 18". In other areas, match adjacent ground cover/terrain as long as there is no interference with facility function.	Mow to 2-inch height. Remove cuttings and dispose			
Insects		✓	Wasps, hornets interfere with operations	Remove			
Tree/brush growth		✓	Growth does not allow maintenance access, interferes with future maintenance activity (e.g., alder), or reduces storage capacity. Otherwise leave alone.	Remove and restore pond bottom			
Fence		✓	Damage to gate/fence, posts out of plumb, or rails bent more than 6 inches.	Repair/replace			
		✓	Brush/weeds along fenceline	Remove brush to within 3 feet of fence			

	Inspection Frequency[1]						
Pond Components	W	A	Condition when maintenance required	Action Required	Satisfactory	Unsatisfactory	Comments
		✓	Erosion/settlement causing opening under the fence greater than 4 inches and 12-18 inches wide or openings along fenceline greater than 8-inch diameter.	Repair			
Embankment and Emergency Spillway							
Spillway		✓	Rock lining down to 1 layer of rock	Add rock to design conditions.			
		✓	Brush, tree (alder) growth on spillway.	Remove and dispose			
Embankment		✓	Downstream face wet, seeps or leaks evident	Plug holes. Contact geotechnical engineer ASAP			
		✓	Any evidence of rodent holes or water piping around holes if facility acts as dam or berm	Eradicate rodents/repair holes (fill and compact)			
		✓	Erosion (gullies/rills) greater than 2 inches around inlets, outlet, and along side slopes. Note evidence of leakage through embankment.	Eliminate source of erosion and stabilize damaged area (regrade, rock, vegetation, erosion control blanket)			
		✓	Settlement greater than 4 inches (relative to undisturbed sections of berm)	Restore to design height			
Control Structure							
Shear gate (*exercise full open/close and inspect)*				Lubricate, repair, or replace			
		✓	Gate rusted, not watertight, or missing	Repair/replace			
		✓	Chain or pull rod missing	Replace			
Riser		✓	Loose, not firmly attached to manhole wall	Repair			
		✓	Not plumb within 10%	Repair			
		✓	Connection to outlet pipe rusted or leaking	Repair/replace			
Maintenance hole		✓	Cannot be opened by one person. Lock missing or damaged	Repair/replace			
		✓	Buried	Excavate			
Orifice plate(s)		✓	Bent, rusted, or missing	Replace			
Structural integrity		✓	Ladder rungs damaged, missing, or misaligned	Repair/replace			

	Inspection Frequency[1]						
Pond Components	W	A	Condition when maintenance required	Action Required	Satisfactory	Unsatisfactory	Comments
		✓	Cracks wider than 0.5" and longer than 3 feet, missing bricks, or any evidence of water leakage	Repair			
		✓	Lock bolts on maintenance hole cover missing	Replace			
		✓	Cracked or broken grate	Replace			
Sediment, trash		✓	Accumulated material within 18 inches of the bottom of the outlet pipe.	Remove/dispose			
Outlet pipe		✓	Submerged or partially submerged	Check for downstream obstruction			
			Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes			
Permanent Pool (wet ponds)							
Undesirable or excessive vegetation				Remove and replant with sedges, rushes, other wetland plants.			
Sediment		✓	Accumulated sediment greater than depth of the sediment zone in forebay (typically 1 foot) plus 6 inches.	Remove, regrade, and replant pond bottom.			
Shutoff Valve and/or Maintenance Drain							
Valve exercised		✓	Valve cannot be operated by 1 person. Valve rusted or not watertight.	Repair/replace			
Sediment		✓	Vertical distance between sediment and drain pipe is less than 6 inches.	Remove and dispose			
Pond Outlet							
Trash rack	✓	✓	Trash or other debris present on trash rack.	Clean and dispose trash			
		✓	Bar screen damaged or missing	Replace			
Inlet/outlet pipes		✓	Root intrusion greater than 6 inches in length or less than 6 inches apart	Root saw pipes			
Receiving water	✓	✓	Erosion damage along banks	Regrade/armour below outlet			

1. Inspection frequency:
   W = Wet season inspections. Inspect the items that are checked once in the early part of the wet season (December) and again near the end of the wet season (March).
   A = Annual inspection. Inspect the items that are checked once each year. To avoid interferences caused by rainfall, the annual inspection should be conducted during the dry season (August - September).